



23, 839/B/1



3078

ESSAY

1878

MINERAL AND CHEMICAL ANALYSIS  
OF THE

MINERAL AND CHEMICAL ANALYSIS

OF THE

1878

MINERAL AND CHEMICAL ANALYSIS

OF THE

MINERAL AND CHEMICAL ANALYSIS

1878  
3073/16  
230  
57

C267



38698.  
*W. H. Patterson*  
*Carlow*  
1832.

ESSAY

ON THE

NATURAL HISTORY, ORIGIN, COMPOSITION,  
AND MEDICINAL EFFECTS,

OF

MINERAL AND THERMAL SPRINGS.

BY MEREDITH GAIRDNER, M. D.

---

Πάν δε αὐτὸν γιγνομένον ὑπ' αἰτίου τινος ἐξ ἀνάγκης γίγνεσθαι· παντὶ γὰρ  
ἀδύνατον χωρὶς αἰτίου γενέσθαι σχεῖν.—PLATONIS TIMEUS.

---

WILLIAM BLACKWOOD, EDINBURGH; AND  
T. CADELL, STRAND, LONDON.

MDCCCXXXII.



PRINTED BY NEILL & CO.  
OLD FISHMARKET.

TO

**ROBERT JAMESON, Esq. F.R.S.L. & E.**

REGIUS PROFESSOR OF NATURAL HISTORY IN THE UNIVERSITY  
OF EDINBURGH, PRESIDENT OF THE WERNERIAN  
NATURAL HISTORY SOCIETY, &C. &C.

*MY DEAR SIR,*

*Allow me to place your name at the head of this little work, as a tribute of esteem for your services as the Founder of the Wernerian Geognosy in Great Britain,—of remembrance for the valuable instructions that I have derived from your prelections,—and of gratitude for the fostering care with which you have promoted my pursuits in the Natural Sciences.*

*Your much obliged*

*Friend and former Pupil,*

**MEREDITH GAIRDNER.**

EDINBURGH, October 25. 1832.





## PREFACE.

---

It has been said by an eminent writer, that, “ at different epochs in the progress of a science, general theories must be formed, otherwise we shall be involved in a labyrinth of particular facts, betwixt which we can trace no connection, nor consequently apply to any useful purpose ;” a truth which is peculiarly applicable to the present state of the literature of Mineral and Thermal Springs in Great Britain. Since the excellent work of Dr SAUNDERS, no general treatise has appeared on the subject, although, subsequent to his time, a total revolution has been effected in the science. Formerly the doctrine of Mineral Waters was considered to involve merely a few details of chemical analysis ; now, however, it has been found to be intimately connected with the great problems of the geognostic structure, and the physical constitution, of the earth.

In the year 1830, I selected for my Inaugural Dissertation the subject “ De Fontibus Calidis.” The investigations into which I was then led, as well as a subsequent visit to some of the Hot Springs in Germany, soon convinced me both of the extent

and interest of the subject, and of the hiatus which here existed in my country's scientific literature. Although far from expecting that this little Essay can fulfil the objects implied in the above quotation, still the few results which I have obtained from my reading and observation, may not be unacceptable to the public, in the want of more elaborate and profound works upon the subject.

Many of the topics touched on will be seen to be mere fragments; but each of these, when observations become more numerous, and our knowledge of the earth's surface more exact and extensive, will probably give rise to distinct and important trains of investigation.

I shall say nothing of the method of arrangement; with very little modification, it is that which I followed in my Thesis. Throughout it has been my earnest endeavour, and not the least of the difficulties attending the work, to limit as much as possible the purely speculative portions, and to furnish the reader with a copious series of facts, from which he may in a great measure deduce his own conclusions.



# CONTENTS.

	Page
INTRODUCTION, . . . . .	1
CHAPTER I.	
COMPOSITION OF MINERAL AND THERMAL SPRINGS, . . . . .	5
SECT. I. Constituents of Mineral Springs, . . . . .	7
Alkaline and Earthy Salts, . . . . .	8
Sulphates, . . . . .	9
Muriates, . . . . .	12
Carbonates, . . . . .	15
Phosphates, . . . . .	18
Fluates, . . . . .	19
Borates, . . . . .	ib.
Nitrates, . . . . .	20
Metallic Salts, . . . . .	ib.
Iron, . . . . .	21
Manganese, . . . . .	23
Zinc, . . . . .	24
Silica, Iodine, Bromine, Strontian, . . . . .	ib.
Free Acids, . . . . .	29
Carbonic Acid Gas, . . . . .	ib.
Carbonic Acid Exhalations, . . . . .	33
Sulphureous and Sulphuric Acids, . . . . .	34
Muriatic Acid Gas, . . . . .	36
Gases, . . . . .	ib.
Sulphuretted Hydrogen, . . . . .	ib.
Hydrogen, . . . . .	39
Azote, . . . . .	ib.
Carburetted Hydrogen, . . . . .	41
Oxygen and Atmospheric Air, . . . . .	ib.
Vegeto-animal Matter, . . . . .	42
Humus extractive, . . . . .	43
Resinous extractive, . . . . .	ib.
Baregine or Animal extractive, . . . . .	ib.

	Page
SECT. II. Amount of the Ingredients of Mineral Springs,	46
Specific Gravity, . . . . .	ib.
Amount of Solid Matters, . . . . .	50
Amount of Gases, . . . . .	53
Constancy of the Impregnation of Mineral Waters, . . . . .	45
Of the Solid Matters, . . . . .	ib.
Of the Gaseous Matters, . . . . .	58
Effect of Seasons, Drought, &c. . . . .	60
III. Combinations of the Constituents of Mineral Springs, . . . . .	62
Upon the Bertholletian theory, . . . . .	64
Upon the theory of the most Soluble Salts, . . . . .	71
Murray's Formula of Analysis, . . . . .	74
Theory of Definite Proportions, . . . . .	76
Causes of the Discrepancies of Analysis, . . . . .	77
Classification of Mineral Springs, . . . . .	81
IV. Temperature of Mineral Springs, . . . . .	87
Supposed greater Specific Caloric, . . . . .	88
Supposed effect of Carbonic Acid in elevating their Temperature, . . . . .	93
Degrees of Temperature of Thermal Springs, . . . . .	95
V. Comparison of Mineral Springs with other Waters, . . . . .	102
Terrestrial Waters, . . . . .	102
Common Springs and Wells, . . . . .	103
River Water, . . . . .	106
Lake Water, . . . . .	108
Sea Water, . . . . .	110
Atmospheric Waters, . . . . .	113
Rain and Dew, . . . . .	114
Ice and Snow, . . . . .	115

## CHAPTER II.

POSITION OF MINERAL AND THERMAL SPRINGS,	116
SECT. I. Geography of Mineral Springs, . . . . .	117
Europe and its Islands, . . . . .	118
Spain and Portugal, . . . . .	ib.
France, . . . . .	122
The Alps and adjacent Countries, . . . . .	128

# CONTENTS.

ix

	Page
Black Forest, Baden, Wurtemberg, Bavaria,	132
Lower Rhine, Eifel, Nassau, Hartz, .	133
Bohemia and Erzgebirge, Silesia, . .	137
Hungary, . . . . .	139
North of Germany; . . . . .	140
Italy, . . . . .	141
Russia and Scandinavia, . . . . .	143
Iceland, . . . . .	144
British Islands, . . . . .	145
Mediterranean Islands, . . . . .	152
Asia and its Islands, . . . . .	155
America and its Islands, . . . . .	163
Africa and its Islands, . . . . .	170
SECT. II. Topography of Mineral Springs, . . . .	173
Relations of Altitude to the Temperature of Springs, . . . . .	ib.
Relations of Altitude to the Composition of Springs, . . . . .	175
III. Geognosy of Mineral Springs, . . . .	179
Thermal Springs, . . . . .	181
Connected with active Volcanoes, . .	181
Unconnected with active Volcanoes, .	185
Continent of Europe, . . . . .	ib.
European Islands, . . . . .	202
Continent of Asia, . . . . .	204
Continent of America, . . . . .	205
General Inferences, . . . . .	206
Connection between Earthquakes and Hot Springs, . . . . .	210
Cold Springs, . . . . .	215
Acidulous and Alkaline Springs, . . .	216
General Conclusions, . . . . .	230
Earthy, Sulphureous, and Chalybeate Springs, . . . . .	232
Saline and Brine Springs, . . . .	237
General Conclusions, . . . . .	242
IV. Rocks formed by Mineral Springs, . . .	245
Calcareous, . . . . .	248
Structure, . . . . .	249
Colour, . . . . .	250



	Page
Composition, . . . . .	252
Position, . . . . .	253
Siliceous, . . . . .	257
Agent effecting the solution of the Silica,	260
Mechanical Deposits of Hot Springs, . . .	362
Disintegrating Agency of Mineral Springs,	266
Reflections on the former State of Mineral Springs, . . . . .	268

### CHAPTER III.

ORIGIN OF MINERAL AND THERMAL SPRINGS,	271
SECT. I. Theories on the Origin of Mineral Springs, .	274
Actual sinking of Shafts, . . . . .	ib.
From Subterranean Fires, . . . . .	ib.
Combustion of Iron-pyrites, . . . . .	275
Combustion of Beds of Coal, . . . . .	278
From their Impregnating Minerals, . . .	281
Theory of Compression, . . . . .	ib.
Galvanic Agency, . . . . .	282
Creative Energies of the Earth, . . . .	284
II. Origin of the Water of Mineral Springs, . .	285
From Subterranean Reservoirs, . . . .	286
From the Atmosphere, . . . . .	287
From the focus of Volcanic Action, . . .	289
From the Ocean or other Masses of Salt-Water,	292
III. Origin of the Warmth of Mineral Springs, .	295
From a general central cause of Heat, . .	296
Proved by common Perennial Springs, .	297
Proved by the Temperature in Mines, .	304
Of the Air, . . . . .	306
Of Subterranean Springs, . . . .	308
Of the Water of Draining Levels, .	310
Of Subterranean Inundations, . .	ib.
Of the Rock, . . . . .	312
Of Artesian Wells, . . . . .	316
From Ancient Volcanic Agency, . . . .	317
From Modern Volcanic Operations, . . .	319

	Page
SECT. IV. Origin of the Ingredients of Mineral Springs, .	322
By Lixiviation, Sublimation, and Solution, .	323
From a general or local cause, . . . .	325
Of the Carbonic Acid, . . . . .	326
Of the Sulphurous and Sulphuric Acids, and Sulphuretted Hydrogen, . . . .	332
Of Muriatic Acid, . . . . .	335
Of Soda, . . . . .	337
Phenomena of Natron Lakes, . . . .	343
Origin of the Great Saliferous Deposits, .	345
Of Lime and Magnesia, . . . . .	350
Iron, Silica, . . . . .	351
Potash, . . . . .	ib.
Iodine, Bromine, Lithion, Fluoric and Phospho- ric Acids, . . . . .	351
Nature of the Interior of the Globe ? . . .	352

## CHAPTER IV.

MEDICINAL VIRTUES OF MINERAL AND THERMAL  
SPRINGS, . . . . . 355

SECT. I. General Effects of the different Classes of Mineral Springs, . . . . .	363
Chalybeate Waters: Oxide of Iron, . . . .	ib.
Sulphureous Waters: Sulphuretted Hydrogen, .	365
Acidulous Springs: Carbonic Acid, . . . .	366
Purging Springs: Sulphates of Soda or Magnesia, .	369
Saline and Brine Springs: Muriate of Soda, .	371
Alkaline Springs: Carbonate of Soda, . . .	373
II. Forms in which Medicinal Springs are employed, .	375
Internal Use, . . . . .	377
Water-Bath, . . . . .	378
Affusion or Douche, . . . . .	381
Vapour-Bath, . . . . .	382
III. Practical Directions for using Medicinal Springs, .	384
Rules for Drinking, . . . . .	385
Rules for Bathing, . . . . .	386
Hygienic and Dietetic Rules, . . . . .	387

## APPENDIX.

	Page
No. I. Hints towards an Agenda for Mineral Springs, .	393
Their Physical Relations, . . . . .	394
Their Chemical Relations, . . . . .	395
Their Medicinal Relations, . . . . .	398
Their History and Literature, . . . . .	ib.
II. On Artificial Mineral Waters, . . . . .	398
Their Preparation, . . . . .	399
Their Relation to Natural Springs, . . . . .	400
Advantages of Artificial and Natural Mineral Springs, . . . . .	402
Principal Establishments for their Use, . . . . .	403
III. Mineralised Mud Baths, . . . . .	404
Sulphureous Mineralised Mud, . . . . .	405
Carbonated Mineralised Mud, . . . . .	407
Ferruginous Mineralised Mud, . . . . .	408
Saline Mineralised Mud, . . . . .	409
Earthy Mineralised Mud, . . . . .	410
Gelatinous Mineralised Mud, . . . . .	ib.
IV. Observations on the Temperature of the Earth in Prussia, . . . . .	411

## TABLES.

No. I. Fixed Elements entering into the Composition of some of the more celebrated Mineral Springs, . . . . .	414
II. 255 of the most celebrated Mineral and Thermal Springs, . . . . .	416



## INTRODUCTION.

PERHAPS there is no subject within the extensive range of natural or medical science, upon which, from the earliest periods to the present times, so many discordant opinions have been entertained, and such extraordinary theories started, as that of mineral waters in general, and more especially of warm springs. The attention of man, at a very early stage of civilization, would be naturally, we might almost say necessarily, drawn to those perennial fountains which, in almost every country, are discharged from the bowels of the earth in boundless profusion, often with great impetuosity, at a very elevated temperature, with various kinds and degrees of foreign impregnation, and which experience soon demonstrated to possess a powerful influence upon the functions of organized beings. But although their importance did not escape the originality of Homer<sup>1</sup>, the industry of Hippocrates<sup>2</sup>, or the comprehensive mind of Aristotle<sup>3</sup>, it is to the light of modern Chemistry and Geognosy—sciences but of yesterday, when freed from the thralldom in which they were so long held by the alchemy of the schools—that we are indebted for more accurate observations, or more general views, without which their history would amount to a mere catalogue of names, or of extravagant hypotheses.

To a superficial observer, the points worthy of attention, with regard to mineral waters, might seem to be comprised within a very narrow compass,—to be confined to a few details on their chemistry, and medical

<sup>1</sup> *Ιλιαδον* χ', v. 147. to 152, where they are described as springing from the waters of the Scamander.—<sup>2</sup> *Περι Ἀεζων, ὕδατων, τοσων.* Sect. 13. and 14, and *Περι Διαιτης* β. Sect. 35.—<sup>3</sup> *Περι Ἀισθησεως και Ἀισθητων.* Cap. 4.

effects. But this is to take a very limited view of the subject, which the more it is investigated, the more extensive and intimate will its relations appear to some of the greatest physical problems still remaining unresolved. Inferences may be drawn regarding the internal constitution of our earth from a patient and accurate comparison of the composition, effects and relations of hot springs, of which, upon a cursory glance, we might not have the smallest conception. Together with the phenomena presented by volcanoes, they are the only channels which reveal to us, or by which we can ever hope to be led to, any certain knowledge of its interior. For the conclusions made from the actual observation of positive facts, surely rest upon a more stable basis than those derived from abstract calculation, where the exclusive method alone can be had recourse to.

But I fear we must confess that the enlargement of the bounds of our geographical knowledge, and of the other productions and operations of Nature, has not contributed in an equal or proportionate degree to that of mineral springs. Observers seem for the most part to have considered them as worthy only of a very cursory and superficial inquiry. Let us hope, however, since the researches of many modern naturalists, and more especially the industry of the Germans, have established their claim to a place inferior to none of the other branches of physics, that their importance will be acknowledged, and their relations more carefully studied in all their bearings. It cannot be denied that the subject is involved in much obscurity; but this, instead of being a motive for inertness, should be a stimulus to renewed exertion;—observing without intermission, and applying the Baconian philosophy at every step, we may arrive at results which now perhaps would be rejected as visionary.

It would be superfluous in me, after the many excellent works already written on the subject, to trace out at length the relations of the doctrine of mineral waters to the other departments of science and art; or to enter into a laboured discussion, in order to prove their importance

to the chemist, the mineralogist, and the physician : these are too obvious to require being further insisted on. To the first they furnish the subjects on which he must exercise the most rigorous analytical skill ; to the second they form a necessary appendage to his methods for distinguishing mineral substances in their solid state ; and to the last they yield inexhaustible treasures of the most valuable therapeutical agents ; or, in the words of the illustrious Hoffmann, the eloquent founder of the science of Thermography, “ Siquidem Deus omnipotens summas et longe præstantissimas in aquis recondidit soterias vires, quarum tanta est excellentia, tantaque utilitas, ut longe multumque omnibus aliis remediorum generibus sint superiores. Foret itaque perutile quinimmo summo opere necessarium, ut ii qui custodes sanitatis audiunt, et morbis mederi student, aquarum salutarium passim scatulentium genuinas et proprias vires imprimis probe et curate explorarent, quo ægrorum incommodis recte consulere possent <sup>1</sup>. ”

We would form very erroneous ideas of mineral waters, did we regard them as a distinct class of natural phenomena, circumscribed by definite and easily assignable limits. On the contrary, they form but one portion of that great mass of waters which either envelopes our globe in the form of invisible aqueous vapour, is condensed into clouds, is distilled upon its surface in the form of rain, snow, and other aqueous meteors, flows along its valleys as streams and rivers, is collected in great reservoirs on its surface, as lakes and seas, or propelled from its interior in the form of springs. They are a still less circumscribed class of bodies, when we regard their composition. Nowhere in nature do we find a chemically pure water,—all contain a greater or less proportion of foreign substances. Indeed this might be expected *à priori*, when we reflect that solution is a principal condition of the reaction of bodies on each other ; that water is the great, the universal solvent, and is continually exposed to the influence of the atmosphere,

<sup>1</sup> De Aquis Min. earumq. salutari virtute. Oper. iii. 131. Fol. 1740.



light, heat, and material substances,—all agents incessantly at work in changing its original purity. Variety of temperature, no less than of position and composition, is another striking feature in this class of bodies ; in this, no less than the others, do they pass by insensible gradations into each other, and into other atmospheric and terrestrial waters. What a contrast between the icy streams which start from the crystal vaults of the glaciers of Switzerland<sup>1</sup>, and the boiling geysers of Iceland ! A still greater difference appears, when we consider the different circumstances of their origin ; in some being immediately influenced by the changes of the atmosphere in respect to temperature, moisture, dryness, &c. ; while others seem to be nearly, if not altogether, independent of this agent, and evince in many circumstances of their position, and the changes which they experience, an intimate connection with phenomena going on at great depths in the interior of the earth.

Conformably to these views, it is my purpose in this essay to consider mineral waters generally, and thermal springs in particular, in their relations to the general cosmical system, as forming one link of that immense chain of atmospheric and terrestrial waters which exercise such an important influence in moulding the external form and intimate composition of this globe which we inhabit, and which is the source of all organic life and activity. In order that all the branches of a field so extensive may each preserve their appropriate place and importance, I propose considering the subject under the threefold aspect of their *composition*, their *position*, and their *origin*, each of which will separate itself into several subordinate divisions, to which I shall add a few remarks on their *medicinal virtues*.

<sup>1</sup> I need not recall to the recollection of the reader the singular purity of the alpine streams of Switzerland, near their sources in the glaciers, which was long ago remarked by Haller in the preface to his *Historia stirpium indigenarum Helvetiæ*: “Nusquam,” says he, “liquidas illas aquas et crystalli simillimas, se mihi obtulisse mihi postquam ex Helvetiæ excessi ; ex scopulis enim nostræ puros silices percolatæ nulla terra vitiantur.”



## CHAPTER I.

COMPOSITION OF MINERAL AND THERMAL  
SPRINGS.

THIS depends upon three conditions, which are intimately connected together: 1. The substances or elements which have been detected in mineral waters by chemical analysis; 2. The quantities of these substances in relation to each other, and their solvent medium; 3. The state of combination in which these substances exist naturally in the mineral water on its first emerging from the bowels of the earth.

All the immense variety which we meet with in this class of springs, depends upon some modification of one or more of these conditions. The first enables us to estimate their physical importance, viewed as a distinct class of mineral products, and, in some respects, to trace the laws of their origin. The two last are of most importance when considered as medicinal or economical agents; for, notwithstanding the great advances which have of late years been made in analytic chemistry, its indications cannot be viewed as the only measure of the importance of a mineral water. It is obvious that it dissolves the bond of connexion which held together the different constituents in their natural state, when it is more than probable they are amalgamated into one compound as yet undiscovered, and incapable of imitation by all the resources of the chemical art. Did we go no further, a strong proof of our ignorance of the real state in which the substances exist in a mineral water, is the discordance of the analyses of different waters by the first masters of the art, who are often forced, after the separation of the constituents into their

simplest proximate elements, to reconstruct a system of combinations upon entirely hypothetical, if not altogether arbitrary, suppositions. To the physician, the last consideration is of indispensable importance. The only method of forming any rationale of their effects in health and disease, is to consider them as acting as a single compound, whose effects are to be judged of by the same train of experience by which he has been able to ascertain those of any one of the proximate compounds detected in them by chemical analysis. Any single salt which he may be inclined to select as characterizing a spring, from its predominance in quantity or superior activity, he will find to be so modified by the presence of other subordinate compounds, that its peculiar qualities are entirely disguised, if not changed altogether. Nay, in many instances, it is not the predominant constituent whose effects stand foremost in the general result on the constitution; this is eminently the case with many thermal waters, such as Teplitz, Karlsbad, Wiesbaden, and Leuk, which all contain a small proportion of iron, from the predominant influence of which, in their effects, they were long classed among chalybeate waters, though its quantity is very trifling when compared with that of the other saline ingredients, and, in some, is scarcely worthy of being estimated at all in a strictly chemical arrangement.

Neither is any chemical analysis capable of expressing the modifications produced in the effects and combinations of the different compounds detected in mineral waters, by an *increased temperature*. This volatile and penetrating agent is continually at work in exalting the activity of substances very insignificant in point of quantity, and in neutralizing that of others much more abundant and naturally of a much more debilitating quality. The importance of taking this agent into account will come to be afterwards considered more fully in estimating the activity and fixity of the gaseous constituents of mineral waters.

Agreeably to these principles, in further discussing the composition of mineral springs, I shall consider:—

The substances which have been detected by chemical analysis: The relative quantities of these substances to each other, and to their solvent medium: The combinations in which these substances naturally exist in the water, or mineral springs, considered in their undecomposed state: The temperatures of mineral springs in relation to each other and ordinary waters: And, lastly, a short comparison between the composition of what are usually denominated Mineral Springs, and other terrestrial and atmospheric waters.

## SECTION I.

### CONSTITUENTS OF MINERAL SPRINGS.

IN no class of waters is their terrestrial origin so distinctly characterised as in this. The most important and essential of these constituents are all substances which enter largely into the composition of the solid crust of the globe; such as the sulphates with a base of soda, lime and magnesia; the muriate of soda; the carbonates of soda, lime, magnesia, iron, free carbonic acid, &c. In the infancy of chemical science, many metals, poisonous metallic and other salts, were supposed to enter into the composition of mineral springs, such as of gold, mercury, copper, lead, arsenic, &c., a delusion which was first dispelled by the labours of Hoffmann, who, in the style of the philosophy of the age, observes, "*Scaturigines delectu quasi instituta ea tantum quæ partibus corporis nostri tam solidis quam fluidis accommodata et amicissima sunt, e terræ visceribus elambunt et in societatem suam admittant*<sup>1</sup>." Falconer long ago disproved, by actual experiment, the existence in these waters of bismuth, tin, lead, copper, and similar metals<sup>2</sup>. Some of the discoveries, however, of modern chemists, render it desirable that they were analyzed more fre-

<sup>1</sup> Op. sup. cit. iii. p. 141.—<sup>2</sup> Essay on the Bath Waters. Lond. 1770–1772.

quently, with a special view to the discovery of those substances which abound in their immediate vicinity. It is only very lately that manganese has been detected<sup>1</sup>. Ten years ago, no one conjectured them to contain strontian and the compounds of fluoric acid, whose existence is now established beyond a doubt<sup>2</sup>. Berzelius has very lately discovered sulphate of zinc in the waters of Ronneby in Sweden. And Fichtel even supposes those springs which rise in the vicinity of mountains, rich in ores of arsenic, not to be entirely destitute of this metal<sup>3</sup>.

Important differences also exist in the general character of these constituents: in some, they are exclusively of an inorganic nature, while, in others, these are associated with extractive matter, nitric and acetic acids; in some their number is inconsiderable, in others their variety is very great. Many warm springs are nearly quite pure water, or scarcely contain four or five different salts, while other cold springs contain twelve, fourteen, and John found in the springs of Gleissen in Brandenburg, no less than sixteen, distinct salts. It is worthy of note, that recent and more accurate analyses are daily increasing the number of the constituents of mineral springs: in none is this more striking than with regard to the hot springs of Karlsbad, in which Berzelius, in 1822, added no less than six new salts to the number of those previously known.

#### ALKALINE AND EARTHY SALTS.

These generally constitute by far the largest proportion of the solid matters in mineral springs; and the great variety in the composition of these waters is generally owing to differences in the nature, quantities, and associations of these salts.

The chief bases of these salts are *soda, lime, magnesia,*

<sup>1</sup> *Becher's Neue Abhandlung über Karlsbad*, 2d edition, Leipzig 1789, first notices its discovery in the tufa deposited by the boiling Sprudel.—<sup>2</sup> It was first observed by Brandes and Krüger in the waters of Selters and Pyrmont.—<sup>3</sup> *Bemerkungen über die Karpathen*, pt. i. p. 149.



*alumina*, all substances which enter largely into the constitution of the solid crust of the globe. More rarely, in much smaller quantity, and, for the most part, only in peculiar localities, do we find *potassa*, which was first discovered by Berzelius in the springs of Adolfsberg in Sweden, but it only occurs in exceedingly minute quantities, being entirely subordinate to soda and other earthy salts, and is only found in those springs which issue from marshy ground. Still more rarely have *ammonia* and *baryta* been met with: and *lithion* has hitherto been detected in but few springs, the principal of which are Ems, Pyrmont, Kreuznach, Aachen, and Karlsbad. It is more than probable that careful analyses of many springs would detect the presence of these minute ingredients where they are at present not even suspected to exist.

The acids most frequently found in union with these bases are the *sulphuric*, *muriatic*, and *carbonic*. Other acids, found much more rarely, and in much smaller quantity, are the *nitric*, *boracic*, *phosphoric*, *fluoric*, and *acetic*.

1. *Sulphates*.—When these predominate in a water, it generally contains also different muriates and carbonates, but only a small quantity of free carbonic acid.

*Sulphate of Soda*.—First in order among the springs where this salt is the predominant constituent, we ought undoubtedly to rank the celebrated *thermal* waters of Karlsbad, which, according to the recent analysis of Berzelius<sup>1</sup>, contain 25.87 parts<sup>2</sup>. One of the springs at St Gervais in Savoy, contains so much as 54.76<sup>3</sup>. The water of Bains in the Vosges, 67.71 of crystallized salt.<sup>4</sup> Other thermal waters are remarkable for their very

<sup>1</sup> Untersuchung der Mineral Wasser von Karlsbad, Teplitz u. Königswart. Übers. v. d. Schwedischen von Dr Gustav. Rose. 8vo, Leipzig, 1825, p. 37.

<sup>2</sup> When not otherwise mentioned, all the numerical indications of the solid matters in mineral springs are expressed in this work as contained in 10,000 parts of water.

<sup>3</sup> *Mathey* sur les Bains de St Gervais, 1818, p. 100.—<sup>4</sup> *Patissier* Manuel des Eaux Minerales de la France, 1818, p. 450.

small quantity, although it is still the predominant constituent. For instances, the springs of Gastein in Switzerland, according to Patissier, do not contain more than 4.07. Those of Plombières in the Vosges, not 2.71: the Geyser of Iceland contains 1.46; and the Rycum waters 1.28, though there silica and muriate of soda are the principal constituents<sup>1</sup>. To these may be added the springs of Olmitello in Ischia, which, according to Wenzl, contain 10.56.

Its quantity is generally much greater in *cold* springs. Thus, the waters of Püllnas in Bohemia, to which the denomination of bitter has been given, from the small quantity of sulphate of magnesia in their composition, contain no less than 124.60 parts<sup>2</sup>. The Franzensquelle at Kaiser-Franzensbad near Eger in Bohemia, contains 33.11: the Louisa spring at the same place, 27.89; and the salt spring, 35.06. In Britain, the springs of Cheltenham contain 81.04<sup>3</sup>; the sulphureous springs of Strathpeffer in Ross-shire, 9.68<sup>4</sup>. Such are a few of the waters in which this salt is the principal constituent, and on which it confers the denomination of *purging waters*, when its peculiar properties are not modified or neutralized by carbonic acid, sulphureted hydrogen gas, or the presence of iron. It exists in subordinate proportion<sup>5</sup> in the greater number of mineral springs, principally in chalybeate and sulphureous waters, in which, in its turn, it exercises important modifications in proportion to its quantity.

*Sulphate of Magnesia.*—It is principally in cold springs that this is the predominant constituent. The springs of Saidschütz and Seidlitz in Bohemia, contain a very large proportion, the former so much as 106.85. In Britain there are the well-known waters of Epsom in

<sup>1</sup> Black, in Edin. Phil. Trans. v. iii. p. 118; 1794.—<sup>2</sup> Wetzler über Gesundbr. u. Heilbader, pt. iii. p. 307; 1823.—<sup>3</sup> No. 4. of the Old Well. Scudamore, Report on the Mineral Waters of England, 1820, p. 177.—<sup>4</sup> Upper Well, Thomson, in Glasgow Medical Journal, May 1828.

<sup>5</sup> Subordinate in a chemical sense, because, not unfrequently, a chemically subordinate ingredient plays the most important part in the medical effects of a mineral water, particularly of many chalybeate and sulphureous springs.

Surrey, which, however, do not contain more than 36.52<sup>1</sup>.

Some hot springs also contain a considerable quantity, although in them it is generally subordinate to other matters, principally sulphate of lime. In the Acqua del Pozzetto, near Pisa in Tuscany, according to Santi<sup>2</sup>, it amounts to 4.41. In France, which is comparatively destitute of strong bitter waters, it exists in many of the thermal springs.

*Sulphate of Lime.*—Its quantity is very striking in many of the thermals of Switzerland, Italy, and the Pyrenees. In Britain, the Bath waters contain, according to Philips, 13.00. Those of Leuk in Switzerland, 23.75; the Acqua del Pozzetto 13.15; the Acqua del Asciano, 8.87; those of Barnabo, 13.65. In almost all the sulphureous thermals of the Pyrenees, it is the principal constituent, such as those of Bareges, St Sauveur, Cauterets, Aigues Chandes, d'Ax, Bagneres de Luchon, Campbo.

In cold springs, it is principally found in the vicinity of gypsum deposits. The sulphureous springs of Eilsen in Hesse contain 17.52, and those of Nenndorf 10.36. Erdmann<sup>3</sup> found in the sulphureous water of Sergiewski, in the government of Orenburg, 12.92; the sulphureous springs of Schlock in Courland<sup>4</sup>, 58.81; the chalybeate of Passy, near Paris, 34.27<sup>5</sup>.

*Sulphate of Alumina*,—is not a very common constituent of mineral waters; but when it does occur, its quantity is often very considerable, and imparts to them very peculiar characters. It is usually associated with some of the combinations of iron, principally the sulphate. In Britain, the Hartfell Spa, near Moffat, contains 16.10; the Isle of Wight aluminous chalybeate, 43.26; the infiltration of the iron-mines at Vicar's Bridge,

<sup>1</sup> Lucas, in Saunders' Treatise on Mineral Waters, 1800, p. 211. —<sup>2</sup> Analis. Chim. delle acque dei Bagni Pisani, 1789, p. 92. —<sup>3</sup> Beiträge zur innern Kenntniss Russlands, pt. 2. 1825, p. 11. —<sup>4</sup> Scherer, Versuch Systemat. ubers. Heilquell. des Russischen Reiches, 1820, p. 51. —<sup>5</sup> Patissier, u. s. p. 385.



near Dollar, 82.94<sup>1</sup>. In the chalybeate of Buckowina in Silesia, 3.80; in the alum spring of Stecknitz in Bohemia, according to Reuss, 1.48, accompanied with 1.44 of uncombined alumina. Its presence is also noticed in the chalybeates of Provins and Cransac in France; in the sulphureous spring of Pisciarelli, near Naples, and the thermals of Lucca, in Tuscany. Blacket found in the vicinity of the warm springs of St Germano, near Naples, a crust two or three inches thick of flocci and fine aciculi, which were composed of lime, and the sulphates of ammonia and alumina<sup>2</sup>.

*Sulphate of Potash*.—This is a recent discovery. Its quantity is but small, and it is generally, though not invariably, accompanied with some of the other sulphates. Berzelius found the Steinbad at Teplitz to contain only 0.01; the drinking spring at Königswart, also in Bohemia, 0.51; the bathing spring at the same place, 0.50; and the Schiersauerling, 0.03; the cold sulphureous spring of Bentheim, 0.57; and that of Schmeckwitz in Saxony, 0.66. Brandes mentions that he found traces in the muriatic-saline spring at Pyrmont; and Reuss found 0.07 in the mineral spring of Wuissikow in Bohemia, which rises in a marsh, where it was associated only with muriates and carbonates. Hermann found<sup>3</sup> the springs of Maschuka in the Caucasus to contain 0.94.

*Sulphates of Lithion and Baryta* have been detected in a few of the Pyrmont springs by Brandes and Krüger<sup>4</sup>.

2. *Muriates*.—These are very abundant in the composition of many mineral and thermal waters.

*Muriate of Soda*.—None of the substances existing in mineral waters occurs more generally diffused, or in greater proportional quantity, than the present. This we should expect, when we reflect on the enormous quantity con-

<sup>1</sup> Connell, in Edin. New Phil. Journ. April 1831, p. 290.—<sup>2</sup> Kastner's Archiv. f. d. ges Natürlehre, v. 11. p. 419.—<sup>3</sup> Poggendorf's Annalen, 1831, No. 7. p. 344.—<sup>4</sup> Pyrmont's Heilquellen, 1826, p. 245. and 338.



tained in the waters of the ocean, and on the immense deposits of rock-salt found in some parts of the globe, and accordingly, it is principally in the vicinity of these last, or of the formations in which they are most commonly found, that these springs present their most characteristic features, more especially when cold.

The following is a synoptic table of the proportion of this salt in a few of those springs regarding which I have been able to obtain precise numerical results :

## THERMAL.

St Nectaire in France, . .	24.20	Berthier.
St Sauveur in do. . .	41.66	Lüdemann.
Wiesbaden in Nassau, . .	60.46	Kastner.
Baden in Baden, . . .	23.07	Osann.
Burtscheid in Nassau, . .	27.82	Manheim.
Gurgitello in Ischia, . .	22.08	Wenzl.
Acqua San Restituta in ditto, .	40.83	Ditto.

To which may be added those of Bains, Luxueil, Bourbon Lancy, Chaudes Aigues, Avene, Balaruc, Bagnoles, Sylvanes, and many others in France; Civita Vecchia in Italy; and several in the Island of Sardinia.

## COLD,

In which the sea-salt is associated with a large proportion of other salts, principally the sulphate and carbonate of soda, and the muriates of lime and magnesia :

Harrowgate in England, . .	49.98 to 130.27	Scudamore.
Cheltenham in ditto, . .	79.67	Ditto.
Leamington in ditto, . .	73.58	Ditto.
Holywell, Lancashire, in ditto,	27.08	Woolnorth.
Dunblane in Scotland, . .	32.85	Murray.
Pitcaithly in ditto, . .	30.80	Ditto.
Moffat, sulphureous, in ditto,	25.23	Thomson.
Roisdorf, near Bonn, . .	19.01	Bischof.
Selters in Nassau, . . .	21.20	Ditto.
Soden in Nassau, . . .	23.49	Mayer.
Kissingen in Franconia, . .	32.57	Goldwitz.
Kannstadt in Wirtemberg, . .	25.79	Kielmayer.
Bramstedt in Holstein, . .	42.07	Pfaff.
Saratoga, State of New York,	25.83	Hosack.

## BRINE SPRINGS,

In which sea-salt is almost the sole constituent, and generally in very large quantity :

Bault, Radnorshire in Wales,	75.87	Daubeny.
Ashby-de-la-Zouche, Leicester-shire in England, . . .	152.00	Ditto.
Middlewich, Cheshire, in ditto,	2049.00	Ditto.
Whealock, Cheshire, in ditto,	1017.00	Ditto.
Shirleywich, Staffordshire, in do.	1703.00	Ditto.
Melksham, Wiltshire, in ditto,	102.90	Ditto.
Pymont, . . . . .	83.71	Brandes & Krüger.
Kreuznach in Lower Rhine, .	168.70	Liebig.
Nenndorf in Hesse, . . .	157.13	Wurzer.
Salzhausen in ditto, . . .	207.62	Liebig.
Elmen, near Magdeburg, . .	198.18	
Schönebeck, . . . . .	199.51	Hermann.

And many others both in the north and south of Germany, such as Ischl, Reichenhall, Halle, Nauheim, Greifswald, &c. ; of Chamossaire, Bex, Wylenbad, &c. in Switzerland. We are informed, also, that salt-springs are very abundant in the Crimea ; and on the south coast of Java they yield, by evaporation, large quantities of salt for the purposes of commerce.

*Muriate of Magnesia*,—is generally associated with the preceding salt, and occurs also in some sulphureous springs. The hot springs of Bath in Britain contain 2.19 ; those of Rennes in France 5.75 ; in those of Bagnères de Bigorre, in the Pyrenees, it is also the chief constituent <sup>1</sup>. In the springs of Kislawodsk in the Caucasus, it is 2.69. Its quantity is also considerable in the springs of Pattenhof <sup>2</sup>.

*Muriate of Lime*,—is generally obtained in very small quantity by the ordinary methods of analysis. It principally presents itself in brine springs, thermal saline, and both hot and cold sulphureous waters. Upon Dr Murray's view of the constitution of mineral waters, which will afterwards come to be considered more in detail, this substance holds a much more important place.

<sup>1</sup> *Sarabeyrouse*, in Alibert's *Precis des Eaux Minerales*, 1826.—

<sup>2</sup> *Scherer*, u. s. p. 75.

Dr Scudamore gives 1.64 to the Bath waters; 3.77 to those of Harrowgate; 39.21 to Leamington. Murray himself gives to the Dunblane waters 24.64; to Pitcaithly, 21.90. The Hartfell spa contains 4.73, associated with the protosulphate of iron <sup>1</sup>. The cold chalybeate of Boulogne was also found by Souquet and Bertrand to contain 8.14 <sup>2</sup>.

*Muriate of Potassa.*—Whenever this substance was found by Wollaston to exist in sea-water, it was conjectured that it might be also found in mineral waters—a supposition which was soon verified by the experiments of several chemists. Berzelius first detected it in the Adolfsberg water in Sweden <sup>3</sup>. Liebig has since found it in the saline spring of Kreuznach, Brandes in the chalybeate of Pyrmont, and Reuss in those of Twer, Andrejapol and Semenowsk in South Russia <sup>4</sup>. In all these situations, its quantity is very minute; only in the Pattenhof water does it attain one part in 10,000.

*Muriate of Alumina.*—Found extremely rarely, and in exceedingly minute quantities. The salt-spring of Kreuznach contains, according to Liebig, 0.577.

*Muriate of Ammonia.*—Said by Grotthuss to exist in the sulphureous spring of Schmoridan in Courland; and by Osann <sup>5</sup> in considerable quantity in the springs of Raab in Hungary. Generally, however, it is a rare constituent, which is not an unimportant fact, when we consider its being a very abundant product of volcanic agency. It may perhaps exist in a greater number of the thermal waters of volcanic districts, but has not been detected, in consequence of the extreme facility of the separation and volatilisation of its base.

*Muriate of Lithion.*—Also found by Liebig in Kreuznach to the amount of 0.075.

3. *Carbonates*—are also very abundant, particularly when their solubility and intimate union with the water are facilitated by an excess of free carbonic acid and an

<sup>1</sup> Thomson, u. s.—<sup>2</sup> Patissier, u. s. p. 402.—<sup>3</sup> Gehlen's Journal der Chem. u. Physik, i. 12, 13.—<sup>4</sup> Scherer, u. s. p. 95, 96. 88.—<sup>5</sup> Osann, Darstellung der Heilquellen Europas, pt. i. 1829, p. 85.

elevated temperature; for which reason they principally characterize thermal and acidulous springs.

*Carbonate of Soda.*—This gives rise to a very peculiar class of springs,—the alkaline. It is usually associated with the sulphate and muriate of soda and the carbonated earths. The thermals of Ems, according to Kastner, contains 27.14; of St Nectaire in France, 20.24; of Vichy, 38.13; Chaudes Aigues, 4.00; Bareges, 9.00; Cauterets, 26.67<sup>1</sup>; Karlsbad, 9.69; Mont d'Or, 4.53; the Steinbad at Teplitz, 3.48; Gurgitello in Ischia, 23.47<sup>2</sup>; Wolkenstein in Saxony, 1.80.

A few of the cold springs in which it is the predominant constituent, are—Vals, in the Department of Ardèche, in France, 51.25<sup>3</sup>; Bilin in Bohemia, 41.18<sup>4</sup>: it is probable, however, that these two quantities include the water of crystallization; those of Fachingen on the banks of the Lahn 21.40<sup>5</sup>; of Geilnau, in the vicinity of the former, 7.94; Tarasp in Switzerland, 52.93, according to Capeller; those of Rosenlowibad, in the canton of Berne, 22.50; of Malvern in England, according to Dr Philip, 0.61.

Although it should not be the principal constituent, this salt enters largely into the composition of nearly all the mineral waters in the different groups of hills on the banks of the Rhine, such as the Eifel, the Siebengebirge, Taunus, and Westerwald; of the provinces of Auvergne and Vivarais in central and south-eastern France; the Pyrenees; the Erzgebirge; and the Bohemian Mittelgebirge.

*Carbonate of Lime.*—Generally associated with sulphate of lime, and a small proportion of carbonate of magnesia. Its quantity is exceedingly various, and scarcely any spring, whether belonging to the class of mineral waters, properly so called, or not, is entirely destitute of it: in some thermal waters, where its solu-

<sup>1</sup> *Ludemann's* *Zugen durch der Pyrenaen*, 1825, p. 338.—<sup>2</sup> *Wenzl*, in *Medicinische Zeitung*, Sept. 1830.—<sup>3</sup> *Berthier*, *Journal des Mines*, xxvii. 141.—<sup>4</sup> *Reuss*, *Naturgeschichte des Biliner Sauerbrunnen*; Prag. 1788.—<sup>5</sup> *Bischof*, *Chem. Untersuch der Mineralwasser zu Geilnau, Fachingen, und Selters in Herzogthum Nassau*.



bility is much aided by a high temperature, and an excess of free carbonic acid, it amounts in the aggregate to an enormous quantity. In all cases, however, from its great fixity, it communicates very peculiar characters to those waters where it is in tolerable abundance, and enables them, in the course of ages, to exercise very considerable formative changes upon the physiognomy of the earth's surface. We need only cite the enormous calcareous vault which forms the receptacle of the boiling Sprudel, and on which rests the whole town of Karlsbad, and the immense masses of travertine of which are built the whole of the splendid edifices of ancient Rome.

The following are a few of the most celebrated thermal waters into which it enters in more than ordinary proportion:—Buxton in England, 1.78; Karlsbad Sprudel, 3.086; St Nectaire, 4.40; Mont d'Or, 1.60; Schlangenbad in Nassau, 1.36; Aix in Provence, 0.66; Kislawodsk in the Caucasus, 11.43.

And among cold springs, all of which belong to the class of acidulous waters, Bilin, 4.42; Königswart drinking spring, 4.22; salt spring at Franzensbad, 2.68; Fachingen, 3.25; Vals, 2.85; Selters, 2.43; Geilnau, 2.59; Marienbad, 9.15, according to Steinman and Reuss<sup>1</sup>; Roisdorf, 3.17; Schwalheim in the Wetterau, 5.77; Soden in Nassau, 7.56; Blumenstein in Canton of Berne, 4.69; Engistein in Berne, 2.76; Pongues, Department de la Nievre in France, 16.29.

*Carbonate of Magnesia.*—Never occurs without the former. Its proportion is generally very small. In the waters of Harrowgate in England, it amounts to 4.80; Bilin, 3.34; Geilnau, 2.91; Roisdorf, 2.80; St Nectaire, 2.40; Fachingen, 2.25; Selters, 2.08; Gurgitello in Ischia, 5.00; Fornello, in the same island, 3.33; Göppingen in Würtemberg, 13.57, according to Kielmayer.

*Carbonate of Alumina.*—This substance would merit very little attention, were it not for the peculiar soapiness it gives to the calcareous waters in which it exists,

<sup>1</sup> Reuss's Marienbad, 1818.

even in very minute quantities,—a quality which was first observed by Pfaff<sup>1</sup>. It is more common in those of Italy than of the north of Europe, such as Pisa and Asciano, in Tuscany.

*Carbonate of Potassa.*—Its relations are nearly the same with the other salts of potash. Reuss found 0.31 in the waters of Wuissokow, and in the chalybeate of Twer so much as 3.13<sup>2</sup>; but this analysis would require to be repeated.

*Carbonate of Lithion.*—This rare substance has been detected by Struve<sup>3</sup> in the thermals of Fms. Berzelius has not been able to prove directly its existence in the Karlsbad Sprudel; but he found it in the proportion of 0.83 in the mother liquor after the crystallization of the Karlsbad salt, which had a specific gravity of 1252.5. The same eminent chemist, however, succeeded in demonstrating its presence in the Franzensbrunn at Franzenbad, near Eger, in the proportion of 0.049; and in the salt spring at the same place, 0.035. In the Ferdinand spring at Marienbad, he found 0.088; and in the Kreuzbrunnen, 0.149. John has also found it at Gleissen in Brandenburg. This substance, and many others of those recently discovered in mineral waters, may not, from the minuteness of their quantities, exert much influence upon the chemical and medicinal properties of the waters in which they occur; but they are highly interesting from their rarity even in the mineral crust of the globe; and more careful analyses, with all the resources of modern chemistry, will doubtless lead to their detection in many waters where their presence is not even suspected, and from thence in the rocks from which these waters flow,—rendering them in some degree indices to the chemist and the geologist of the mineral treasures hid in the bowels of the earth.

4. *Phosphates.*—These are the discovery of modern chemists; but to these, as well as to the alkaline and

<sup>1</sup> *Über die Mineralq. bei Bramstedt* 1810, p. 45.—<sup>2</sup> Scherer, u. s. p. 104.—<sup>3</sup> *Über Nachbildung Künstlichen Heilquellen*, pt. i. p. 29; pt. ii. p. 108.

earthy salts which are to follow, we may perhaps apply the foregoing observations. Berzelius has detected phosphates of lime and alumina in the Karlsbad Sprudel, the former to the amount of 0.0022, the latter 0.0032; a trace of phosphate of alumina in the acidulous spring at the same place; in the Steinbad at Teplitz, 0.020 of phosphate of soda: he found phosphate of alumina in all the springs at Königswart; the largest quantity was in the drinking water, where it amounted to 0.026. The same eminent chemist also found the phosphates of lime and alumina in the springs of Franzenbad near Eger, and of phosphate of alumina at Marienbad<sup>1</sup>; also phosphate of potash in the mineral waters of Adolfsberg in Sweden. Bischof detected phosphate of soda in the three alkaline and saline waters of Geilnau, Fachingen, and Selters, in the quantities of 0.366, 0.0092, 0.358<sup>2</sup>; Wurzer found phosphate of alumina in the chalybeate of Hofgeismar in Hesse, and phosphate of soda in the sulphureous water of Nenndorf. Brandes found phosphate of potash in the Pyrmont waters; and, lastly, Hermann found 0.03 of phosphate of alumina in the thermals of Maschuka.

5. *Fluates*.—Berzelius found 0.032 of fluato of lime in the Karlsbad Sprudel, and traces of the same substance in the acidulous spring of the same place and at Franzenbad. Struve detected it at Selters and Ems; and Wurzer found a trace at Nenndorf. It enters in considerable proportion into the Sprudel sinter, amounting, in two specimens examined by Berzelius, to 9.9 and 6.9; and also in the Wiesbad Sinter.

6. *Borates*—have not been found in the mineral waters of the north of Europe, but in some of those in Italy, especially Siena. I need not remind the reader of their occurrence in many of the *lakes* of Tibet and Persia.

<sup>1</sup> Berzelius, u. s. pp. 37, 88, 93, 99, 145, 144.—<sup>2</sup> Bischof, u. s. pp. 33. 71. 96.



7. *Nitrates*.—These salts scarcely ever occur in mineral waters properly so called : when they do exist, their presence is only temporary, and these waters rise in the vicinity of deposits of animal and vegetable remains in a state of decomposition, and are subject to frequent changes, both in quantity and impregnation, with the changes of the seasons. However, we are informed of a singular fact, that there is a district of Hungary, between the Carpathians and the Drave, where all the springs, for the space of about 300 miles, contain a small proportion of the nitrate of potash<sup>1</sup>. Patissier mentions the occurrence of nitrates in the thermal waters of Ofen and St Alban; and Morell<sup>2</sup> says that he has detected the nitrate of lime in those of Pfeffers, but which would seem to be rendered doubtful by the more recent analysis of Capeller. Buchner seems to consider as pretty constant the proportion of nitrates in the mineral water of Münchhof<sup>3</sup>.

Their quantity is generally more considerable in the water of wells: thus Berzelius found no less than 4.99 of nitrate of potash in one of the wells of Stockholm, along with some nitrate of lime.

#### METALLIC SALTS.

Very few have as yet been detected by the more accurate researches of modern chemists; although in this, as upon many other subjects, there seems a disposition to return to the opinion of the ancients, attacked with such vigour, about the middle of last century, by the celebrated Hoffmann. Their number is daily increasing, and will probably continue to do so, when we reflect on their very general diffusion in the different rocky masses which form as it were the matrix of mineral waters.

Their quantity is in all cases but small, if compared with that of the different salts we have been examining; but, from their very marked qualities, they impress their

<sup>1</sup> Osann, u. s. p. 92.—<sup>2</sup> Chemische Untersuch. der Gesundbn. u. Bäder der Schweiz. 1788, p. 145–155.—<sup>3</sup> Schweigger, Journ. de Chemie, xlv. 417.



characteristic features in a very decided manner upon those waters into which they enter in a more than ordinary proportion.

1. *Iron*.—This metal, which enters so largely into the composition of the solid crust of the globe, and is so universally diffused, holds a no less prominent rank among the constituents of mineral waters. Its quantities, its combinations, its associations, are all exceedingly various. Scarcely any spring is entirely destitute of it. In most instances it is in the state of the carbonate of the protoxide, and is deposited in large quantity in the form of oxide, on the water coming in contact with the external air, owing to the escape of the excess of carbonic acid above that which the water is capable of holding in solution under the ordinary atmospheric pressure<sup>1</sup>; indeed, by varying in our data the two conditions of heat and carbonic acid, we can set no limits to the quantity of the oxide of iron which may be taken up by water in the interior of the earth. In other cases it is in union with sulphuric acid; in which case it is frequently associated with sulphate of alumina. More rarely is it combined with muriatic acid<sup>2</sup>. In all cases it is a chemically subordinate ingredient; but in those wa-

<sup>1</sup> A different view of this process from that generally received, and which is hinted at above, is given by Longchamps (Alibert, *Precis*, p. 302). He says, that it is not correct to suppose that it is always the carbonic acid which holds the iron in a state of solution in waters, for we find it in many which do not contain this acid. In fact, hardly do these waters emerge from the bosom of the earth, when they precipitate the greater part of the oxide of iron which they contain. Now, if the oxide had been dissolved by the carbonic acid, as this acid is retained by the water with considerable force when in small quantity, it would not escape at the moment of the ferruginous water coming in contact with the air; but since this small quantity of carbonic acid would have sufficed to dissolve the oxide of iron in the bowels of the earth, it would also suffice to dissolve it out of it. Very often, in mineral waters, the oxide of iron is found combined with lime, so that this oxide performs the functions of an acid with regard to this base; this acid M. Longchamps denominates the *ferric*. Thus most of the calcareo-ferruginous sediments formed by mineral waters would be *ferrate of lime*, instead of oxide of iron and carbonate of lime, as hitherto supposed.

<sup>2</sup> As in the aluminous chalybeate of Buckowina in Silesia.

ters in which it is medicinally predominant it forms a distinct class, called the *Chalybeate*, and when associated with a large quantity of free carbonic acid, the *Acidulo-chalybeate*. Besides these, it enters in considerable proportion into many saline, sulphureous, acidulous, and thermal waters, without on that account constituting a true chalybeate. Its quantity is, in general, smallest in thermal waters; but it ought not to be forgotten that all these divisions are quite artificial, as all of them in nature pass into each other by insensible transitions.

Having premised these general remarks, I shall proceed to indicate its quantity in a few waters remarkable either for a more than ordinary proportion of this metal, or which are generally celebrated. After the example of Berzelius, Bischof, and Berthier, I shall constantly state the results as oxide of iron, and not as carbonate, or any of its other combinations.

## THERMAL.

Bath in England, . . . .	0.0271	Philips.
Bourbon l'Archambault in France	2.579	Patissier.
Mont d'Or in ditto, . . . .	0.10	Berthier.
Vichy in ditto, . . . .	1.385	Longchamps.
St Nectaire in ditto, . . . .	0.14	Berthier.
Chaudes Aigues in ditto, . . .	0.15	Ditto.
Campagne in ditto, . . . .	0.1573	Patissier.
Karlsbad Sprudel in Bohemia, .	0.022	Berzelius.
Teplitz Steinbad in ditto, . .	0.03	Ditto.

And many others; as Rennes les Bains, Audinac, Malou, Capus, and St Alban, in France; Ems, Schlangenbad, Wiesbad and Leuk, in Germany. Generally speaking, in thermal waters the quantity of iron seldom exceeds 0.01.

## COLD.

Tunbridge in England, . . . .	0.381	Scudamore.
Harrowgate (Oddy's saline chalyb.) in do.	0.411	Ditto.
Isle of Wight (aluminous chalyb.) in do.	14.79	Marcet.
Holywell, Lancashire, in England, .	2.396	perox. ir.
		Woolworth.
Hartfell Spa, near Moffat, in Scotland,	0.825	Thomson.
Ditto No. 2. . . . .	34.2	Ditto.

Vicar's Bridge, near Dollar, Scotland,	312.0	Connel. <sup>1</sup>
Dunblane in ditto, . . . .	0.233	Murray.
Forges in France, . . . .	1.128	Robert.
Aumale in ditto, . . . .	2.50	Diezengremel.
Passy in ditto, . . . .	0.679	Deyeux.
Vals in ditto, . . . .	0.06	Berthier.
Alexisbad, Bernburg, in Germany, .	2.348	Graefe.
Buckowina in Silesia (Lower Spring)	2.090	Lachmund.
Liebenstein in Thuringia, . . .	1.66	Trommsdorff.
Godelheim (bathing spring), . . .	1.489	Witting.
Lauchstadt, . . . .	1.018	
Spaa, . . . .	0.746	Monheim.
Pymont (drinking spring), . . .	0.611	Brandes.
Kissingen, . . . .	0.421	Vogel.
Bruckenaus in Franconia, . . . .	0.210	Schipper.
Karlsbad (acidulous spring) . . .	0.03	Berzelius.
Königswart (drinking spring) . . .	0.38	Ditto.
Bilin, . . . .	0.10	Reuss.
Geilnau, on the Lahn, . . . .	0.128	Bischof.
Fachingen on ditto, . . . .	0.077	Ditto.
Selters in Nassau, . . . .	0.124	Ditto.
Marienbad, Caroline well, . . . .	0.369	Steinman & Reuss.
Engistein, Canton of Bern in Switzerland,	0.875	Pagenstecher.
Schmerikon, Canton of Gallen in ditto,	1.086	Hüttenschmidt.
St Catarina, Canton Veltlin in ditto,	2.466	Demagri.
Lipewsk in Russia, . . . .	1.0 to 2.0	Scherer.
Ballstoun, New York, United States,	3.332	Hosack.

2. *Manganese*—has only obtained a place among the constant and regular constituents of springs within the last ten years; although Dr Becher, so far back as 1789, notices its existence in the calc-sinter of the Karlsbad waters<sup>2</sup>. It was discovered first in chalybeate waters, which contain a much larger proportion than any other class, exhibiting another proof of the close connection between mineral waters and other mineral products in which manganese is found associated with iron more frequently than with any other substance. It has been, however, detected in saline and sulphureous waters; as Saisdschütz and Kreuznach, Nenndorff and Eilsen.

The Karlsbad Sprudel contains, according to Berze-

<sup>1</sup> This can scarcely be called a true mineral water, being somewhat analogous to the pools in copper mines of England and Sweden, which hold copper in solution, a substance not found in true mineral springs. As it is, however, an example of a purely natural process, I have deemed it worthy of a place among the other waters.

<sup>2</sup> Becher, u. s. p. 143.

lius, of oxide of manganese 0.0052. The Maschuka springs 0.0109. It also exists in the thermals of Mont d'Or, Luxueil, d'Aix, Ems and Schlangenbad.

The waters of Königswart 0.043; of Franzensbad 0.035; of Marienbad 0.074 to 0.031. A trace in intimate union with oxide of iron in the waters of Geilnau, according to Bischof; also, in the acidulous and chalybeate waters of Pyrmont, Cudowa, Potsdam, Adolfsberg, Cransac; and, according to Scherer, in the chalybeates of Semenowskaja, Jasinskow, Wiusskow, Andrejapol, and Kuppis in Russia; and in those of Kislawodsk 0.07.

3. *Zinc*.—Berzelius has very lately detected the sulphate in the mineral water of Ronneby in Sweden<sup>1</sup>.

Copper has been detected in no true mineral water, but it has been found in solution in the pools of copper mines, as in Glamorganshire in England, Fahlun in Sweden, Neusohl in Hungary. Ficinus detected a minute quantity in the calcareous vault of the Karlsbad Sprudel, but it has not been found in the water itself.

#### SILICA, IODINE, BROMINE, STRONTIAN.

1. *Silica*.—The quantity of this very insoluble earth in mineral waters is always inconsiderable, seldom exceeding one or two parts in 10,000. We must, however, carefully distinguish between a state of true chemical solution and mere fine mechanical suspension. It is found in a state of minute division suspended in a great variety of cold springs, both mineral and common, and on some occasions in no inconsiderable quantity. I need only cite in our own country the Holywell water in Lancashire, which yields no less than 4.107 of a residuum, insoluble in muriatic acid, principally silica<sup>2</sup>. John has also observed a tolerably large proportion in the Louisa spring at Berlin. It is a fact not unworthy of notice, that Si-

<sup>1</sup> Brandes Archiv. xxvi. 126.—<sup>2</sup> Journal of Royal Institution, xviii. 188; 1825.



lica is seldom found suspended in those waters, generally of remarkable purity, which flow over the rocky and highly siliceous channels of mountainous districts, and which are exposed to perpetual agitation in their progress, a circumstance which might seem to promote the separation of siliceous particles from their beds. On the contrary, it is usually in the springs of low calcareous and sandstone districts that these matters occur.

True solution and intimate combination with the other constituents is met with only in thermal waters, or in those cold springs which hold in solution a large quantity of carbonate of soda, or discharge a superabundance of carbonic acid. The most striking examples are the well known boiling springs of Geyser and Rycum in Iceland, where it amounts to one-half of all the solid constituents, the former containing 5.40, the latter 3.73 <sup>1</sup>. In England, the King's bath at Bath, contains only 0.274. Its proportion is very great in many of the thermal waters of central France; those of Mont d'Or contain 2.10; of Chaudes Aigues 1.16; of St Nectaire 1.00; of Vichy 0.680 <sup>2</sup>; of Plombieres, 1.805; of Evaux, 0.678; of Baresges, 0.213; of Canterets, 0.584; St Sauveur, 0.237 <sup>3</sup>; In Germany, the Karlsbad Sprudel, 0.751; Teplitz, 0.42; Baden in Baden, 2.864, according to Struve; Warmbrunn in Silesia, 0.977; Gastein in Salzburg, 1.059, according to Mayer; Ems in Nassau, 0.556. In the island of Ischia, the hot springs of Gurgitello, 0.556; of Olmitello and San Restituta, 0.417. Of the Caucasian thermals, Maschuka, 0.73; Eisenberg, 0.57; Kumgara, 0.32; Catherine springs, 0.23.

<sup>1</sup> *Black* in Edin. Phil. Trans. iii. 118; 1794. This example is of so much importance in estimating the origin of the silica, that Ilshal subjoins a table of the composition of these celebrated waters:

	Geyser.	Rycum.
Silica, . . . . .	5.40	3.73
Muriate of Soda, . . . . .	2.46	2.90
Dry Sulphate of Soda, . . . . .	1.46	1.28
Caustic Soda, . . . . .	0.95	0.51
Alumina, . . . . .	0.48	0.05
	<hr/> 10.75	<hr/> 8.47

<sup>2</sup> *Longchamps* in Alibert's *Precis.*—<sup>3</sup> *Bischof*, u. s. p. 227.

In cold mineral waters its quantity is not so great as in the thermal. It varies greatly in regard to the intimacy of its union with the other constituents. The following are a few of those in which it may be regarded as in a state of real chemical combination. In Britain, St Anne's Well at Malvern, contains only 0.081 of insoluble residue which may be considered as consisting principally of this earth; the Isle of Wight aluminous chalybeate, 0.958. In France, those of Vals, 1.16; of Enghien les Bains, 0.521. In Germany, the cold acidulous spring at Karlsbad, 0.47, where it constitutes a third of the whole solid matter remaining after evaporation; Selters, 0.376; drinking spring at Königswart, 0.850; Franzensbrunn at Franzensbad, 0.48; Roisdorf, 0.21; Fachingen, 0.114; Geilnau, 0.143; Ferdinand's spring at Marienbad, 0.678; Pyrmont, according to Brandes, 0.136.

2. *Iodine*.—This rare substance being found by Balard in the water of the Mediterranean sea<sup>1</sup>, and by Pfaff in that of the Baltic<sup>2</sup>; it was natural to look for it, if not in saline waters generally, at least in brine springs which resemble sea water most nearly, and serve as the connecting links between the modern, and those remnants of the ancient ocean, which form immense rocky masses in the bowels of the earth. It was in 1820<sup>3</sup>, however, that M. Angelina discovered its presence in the saline waters of Sales, in the province of Voghera in Piedmont, which contain one-twelfth of muriate of soda, and where it was till then unknown, although these waters had been twice before carefully analyzed. It always exists naturally in mineral waters in the form of a hydriodate, generally of soda, more rarely of potass.

It has since been detected in others of the Italian springs; as by Cantu in those of Genesio and Castel Nuovo d'Asti<sup>4</sup>; and by Egidi in some springs near Ascoli, in the

<sup>1</sup> Annales des Chim. et de Phys. xxviii. 178.—<sup>2</sup> Schweigger's Jour. d. Chem. N. S. xv. 32, 225.—<sup>3</sup> Journal des Mines, viii. 293.—<sup>4</sup> Annales de Chem. et de Phys. xxviii. 221.

Papal territory<sup>1</sup>. W. Copeland, Esq. of Blackwood, has the honour of having first detected its presence in the waters of Britain, having found minute traces of hydriodate of potass in the carbonated chalybeate of Bonnington near Edinburgh<sup>2</sup>. Dr Daubeny has subsequently, by an elaborate series of researches, proved its existence in a large proportion of the saline and brine springs of England<sup>3</sup>; but the largest quantity he was able to detect, did not exceed probably a grain in 10 gallons of water: this was in Robin's Well at Leamington, in Warwickshire. It was also found at Cheltenham, in the old well, where it was estimated at about a grain to 60 gallons. Although generally found on the Continent, in largest quantity in brine springs, this appears not to be the case in England, for none was found at Ashby de la Zouch in Leicestershire; at Droitwich in Worcestershire, nor at Shirleywich in Staffordshire; and the largest quantity (at Nantwich in Cheshire) was estimated at only a grain in 12 gallons. Nor is it, as has been generally supposed, at all proportional to the quantity of muriate of soda in a spring; for its greatest proportion to the chlorine in the brine springs of England, was only 1.96000, while in one of the Leamington springs, it amounted to 1.12000<sup>4</sup>; nay, it is even found where the muriate of soda is altogether wanting, as at Llandridod in Radnorshire, a water which contains only the muriates of lime and magnesia. It may be observed that no trace of iodine was found in a saline chalybeate at Llandridod, and another at Bualt in Radnorshire, which are strikingly contrasted with that examined by Dr Turner.

In Germany, the largest quantity has been found in the brine springs of Salzhauzen, near Frankfort, where, according to Graff, it amounts to 0.77; of Heilbrunn in Bavaria, also, 0.77; and of Kreuznach, near Mainz, 0.05, according to Liebig. We may add to these, those of Colberg, Hall, Schönebeck, Salzuffeln, and Halle. In

<sup>1</sup> Schweigger's Jour. d. Chem. N. S. xv. 128.—<sup>2</sup> Edin. New Phil. Jour. i. 159.—<sup>3</sup> Phil. Trans. 1830; pt. 2. p. 223.—<sup>4</sup> See Table sub. joined to Dr Daubeny's Paper.



all of which it exists in the form of the hydriodate of soda.

In South America, Boussingault has found traces of the hydriodate of magnesia in the saline waters of Antioquia in Peru<sup>1</sup>; and Dr Mill mentions the occurrence of hydriodate of potass in a spring 16 leagues from Popayan, at an altitude of 10,000 feet above the level of the sea, and between 80 and 90 miles distant from it in a straight line<sup>2</sup>.

I may just recal to the recollection of the reader, that not a trace of iodine has yet been found in rock-salt.

3. *Bromine*.—This active substance is generally co-existent with the former in saline waters, as in the sea where it was originally discovered by Balard. Indeed, it seems to be still more exclusively found in brine springs than iodine, and it often far exceeds the latter in quantity. Its most common combination is the hydrobromate of magnesia. The largest quantity in the brine springs of England, was in those of Middlewich in Cheshire; Nantwich; Ashby de la Zouch, and Shirleywich. In the first, Dr Daubeny found it to exist in the proportion of 1.337; in the second, of 0.903; in the third, 0.669; and in the last, 0.617. None was found in those springs at Cheltenham which contained iodine, whilst in the Pittville spring, the only one which does not contain it, every 6 gallons contain about a grain of bromine. A distinct trace was found in the water of Llandridod, which, as above mentioned, contains none of the muriate of soda.

Bromine is found in several of the French saline waters, as in those of Bourbonne les Bains. In Germany, Kastner found the brine spring of Greifswald in Pomerania, to contain 0.023 of bromide of magnesium<sup>3</sup>. It has also been detected in those of Rosenheim in Bavaria, Kreuznach, Halle, Salzuffeln, Rehme, Werl, Schönebeck, Kissingen in Franconia, Wiesbad, and Ems.

<sup>1</sup> Alibert's *Precis*, p. 499.—<sup>2</sup> *Journal of Royal Institution*, N. S. iii. 384.—<sup>3</sup> *Kastner Archiv*. xviii. 299.



4. *Strontian*—has lately gained a place among the constituents of mineral waters. Its quantity of course is very minute. It is usually in combination with carbonic acid, and in intimate union with the carbonate of lime. Berzelius found the Karlsbad Sprudel to contain 0.010 of the carbonate; it also exists in the thermals of Aach and Burtscheid. Brandes and Krüger found in the Pyrmont water, 0.029; the bathing spring at Königswart, contains 0.020; the Franzenbrunn at Franzensbad, 0.004; the Ferdinand spring at Marienbad, 0.007; and lastly, in the Selters water<sup>1</sup>.

#### FREE ACIDS.

1. *Carbonic Acid Gas*.—This is the most common of all the gaseous constituents of mineral waters; indeed, none are quite destitute of it, not even common spring water, although in these extreme cases its quantity is very small, perhaps not more than 1 or 2 cubic inches<sup>2</sup>. In other cases its quantity, though more considerable, is entirely subordinate to the other constituents, both in respect to its influence on the composition and medicinal effects of the water, although it often modifies these in a very important manner, as is well seen in what are called acidulous chalybeates. It is only when its quantity so far exceeds that of all the others, as to hold the most important place in the composition and effects of a water, that it forms the basis of a particular class,—the *Acidulous*, which are themselves in their turn very much modified by the quantities and nature of the subordinate ingredients. This class of waters, it is obvious, is not circumscribed any more than any other by strictly definite limits; for there is not only an insensible gradation in the absolute quantities of carbonic acid contained in different springs, but even the very same quantity which

<sup>1</sup> *Struve* über Nachbildung Künstlichen Heilquellen, pt. 1. p. 29.

<sup>2</sup> When not otherwise mentioned in this work, all the indications of the quantities of gases in mineral waters are to be considered as expressing the number of cubic inches of gas in 100 cubic inches of water.

in one water may suffice to give it the acidulous character, may in another be entirely subordinate, or even quite unimportant, on account of the presence of other active, solid, or gaseous matters. All the divisions of carbonated springs, according to the quantities of acid, into the rich, which contain from 30 to 60; the richer, from 60 to 100; and the richest from 100 to 200<sup>1</sup>, are therefore to be considered as entirely arbitrary. Generally speaking, the quantity of carbonic acid is inversely as the temperature of a water, the higher the temperature the smaller the quantity of acid, and *vice versa*. This, however, depends much on the quantities of the concomitant saline constituents, especially of the carbonates, which, when abundant, enable a water to take up a much larger quantity of the acid; and to retain it in solution at a much higher temperature, than but for them it would be capable of doing.

Important differences also exist in regard to the cohesion of the carbonic acid to the water. Some, although they issue from the bowels of the earth fully saturated, and discharging large quantities of the superabundant acid into the atmosphere, by no means contain the quantity which water is capable of retaining in solution, under the ordinary atmospheric pressure. These springs are generally remarkable for a very small proportion of solid constituents. A striking example is found in the Karlsbad acidulous spring, which possesses only 1.42 of solid matters, one-third of which is silica, and was found by Lampadius to contain only 88 of carbonic acid, although the beautiful experiments of Theodore de Saussure have shewn that distilled water, under the ordinary weight of the atmosphere, is capable of taking up 106 when fully saturated. The speedy precipitation of the oxide of iron in highly acidulated chalybeates, is another proof of the extreme fugitiveness of this gas: this is eminently the case with the waters of Hartfell, Cheltenham, and Tunbridge, in Britain<sup>2</sup>; of Fideris, St Catarina, and Engistein in Switzerland<sup>3</sup>;

<sup>1</sup> Osann, u. s. p. 111.—<sup>2</sup> Saunders on Mineral Waters, 1800, pp. 248, 327.—<sup>3</sup> Rüsçh, Betrachtung der Schweizerischen, Mineralwasser, 1826, pt. 2, p. 339.

of Imnau, Lauchstädt, and Langenau in Germany<sup>1</sup>; and in most of the acidulous springs of Silesia, and the County of Glatz. The analysis of the gaseous matters of these waters, after the agitation of a long journey, are of course of no value, not to mention the importance of its being attended to in the medicinal use of these waters.

In other cases, the carbonic acid is very intimately combined with the water. Thus Wetzler found the chalybeate water of Steben in Franconia, after having been kept for three years bottled in a cellar, to be still perfectly clear, without the slightest precipitation of oxide of iron, which was found on analysis to be still in combination with its carbonic acid. The same chemist<sup>2</sup> mentions, that no iron was precipitated from the sulphureo-acidulous water of Bocklet in the same country, although exposed in an open vessel to the air for twenty-four hours, and at the expiry of that period, many bubbles of gas were still disengaged by agitation. Bergman found the water of Driburg to contain still 95 of carbonic acid after it had been subjected to the agitation of a long journey; and Suadicani remarks of the same water, that after three years there was no ochry deposit, which only took place after having been exposed for six hours to the air and the sun's rays<sup>3</sup>. The same advantage is possessed by the Pymont water; Westrumb found it to have lost only 0.66, after having been kept in bottles for three months, and another specimen to have lost only 0.12 at the end of a whole year. The same eminent chemist found the Selters water also to retain its carbonic acid with great obstinacy, although its small proportion of iron is precipitated with great facility. The springs of Kissingen, Spaa, Franzensbad, and Recoaro, in Lombardy, are all remarkable for their strong retention of this gas.

<sup>1</sup> *Wetzler*, Gesundbrunnen u. Bäder des Königreiches Baiern, 1823, pp. 29, 30.—<sup>2</sup> Additions to his work on the Medicinal Waters of Bavaria, p. 93.—<sup>3</sup> *Hufeland*, Journ. d. Praktisch. Heilkunde, xiv. 11–14; xlviii. 34; lii. 95.



The following is a tabular view of a few of the springs most remarkable for their carbonated impregnation :—

## THERMAL.

		Temp.	
Bath in England, . . . . .	4.16	114° F.	Philips.
Bristol in do. . . . .	12.99	74	Carrick.
Buxton in do. . . . .	0.649	82	Scudamore.
St Nectaire in France, . . . . .	400.0	75	Alibert <sup>1</sup> .
Karlsbad in Bohemia, . . . . .	110.0	165	Berzelius.
Gurgitello in Ischia, . . . . .	89.14	122	Giudice <sup>2</sup> .
Carratraca in Spain, . . . . .	10.70	66	Alibert.
Maschuka in the Caucasus, . . . . .	60.9	118	Hermann.
Eisenberg in do. . . . .	32.7	103	Ditto.
Petersquellen in do. . . . .	2.0	195	Ditto.
Schlangenbad in Nassau (Schachtbrun), . . . . .	6.0	87	Kastner.
Ems in do. (Kränchesquelle), . . . . .	59.9	86	Ditto.
Ditto (at Wall of Lahn), . . . . .	42.1	123	Ditto.
Wiesbaden in do. (No. 1.), . . . . .	19.7	158	Ditto.

## COLD.

Tunbridge in England, . . . . .	3.485	Scudamore <sup>3</sup> .
Harrowgate in do. (old sulphur well), . . . . .	4.125	Ditto.
Cheltenham in do. (old well), . . . . .	12.50	Fothergill, 1788.
Piteaithly in Scotland, . . . . .	3.463	Murray.
Andabra in France, . . . . .	100.0	Berard.
Engbien les Bains in do. . . . .	0.674	Longchamps <sup>4</sup> .
Godelheim in Germany, . . . . .	224.9	Witting.
Cudowa in county of Glatz, . . . . .	202.6	Mogalla.
Pyrmont in Germany, . . . . .	151.1	Brandes.
Königswarth in Bohemia, . . . . .	139.1	Wetzler.
Schwalheim in the Wetterau, . . . . .	129.0	Wurzer.
Bocklet in Franconia, . . . . .	112.5	Vogelmann.
Franzensbad in Bohemia, . . . . .	88.67	Trommsdorff.
Geilnau on the Lahn, . . . . .	163.2	Bischof.
Fachingen on do. . . . .	134.8	Ditto.
Selters in Nassau (Nieder), . . . . .	108.7	Ditto.
Liebenstein in Thuringia, . . . . .	109.9	Trommsdorff.
Tarasp in Switzerland, . . . . .	109.9	Capeller.
Kissingen in Germany, . . . . .	85.85	Vogel.
Imnau in Wurtemberg, . . . . .	89.28	Kielmayer.
Alexandersbad, . . . . .	94.09	Hildebrandt.
Bilin in Bohemia, . . . . .	74.69	Reuss.
Schwalbach in Nassau, . . . . .	73.83	Rube.

<sup>1</sup> I have assumed the coldest spring to be that which contains this large quantity of gas, which is not particularly specified; there are seven springs, ranging from 74°–104° F.

<sup>2</sup> Viaggio Medico. Half of the acid escapes at 144°, and the whole at 167°.

<sup>3</sup> After being heated to 114° F., it contained 2.736.

<sup>4</sup> Parts by weight in 10,000 of water.



Spaa in Germany, . . . . .	74.45	Monheim.
Ballstown, State of New York, . . . . .	300.0	Hosack.
Kislawodsk in the Caucasus, . . . . .	151.2	Hermann.
Dinkhold in Nassau, . . . . .	143.9	Kolb.
Oberlahnstein in do. . . . .	55.6	Amburger.
Marienfels in do. . . . .	92.5	Kastner.
Soden in do. . . . .	88.0	Meyer.
Cronberg in do. . . . .	106.2	Ditto.
Montabaur in do. . . . .	55.8	Jacobi.
Braubach in do. (Salzborn), . . . . .	58.4	Bruckmann.
Langenschwalbach (Weinbrunn), . . . . .	89.1	Kastner.
Marienbad in Bohemia (Kreutzbr.), . . . . .	125.0	Struve.
Saidschütz in do. . . . .	20.9	Ditto.
Püllnas in do. . . . .	6.9	Ditto <sup>1</sup> .

This is perhaps the most appropriate place to consider another form in which carbonic acid is discharged in large quantities from the interior of the earth,—not in a state of solution, or associated with water at all,—but in the form of *gaseous springs*, or *solfataræ*. Indeed Berthier has hazarded an opinion, which is perhaps the most correct view of the subject<sup>2</sup>, that the gas which escapes with such profusion from many acidulated thermal waters, on their coming in contact with the external air, has never been in a state of combination with the water, but is an independent stream of carbonic acid discharged by the same fissure as the mineral water, and is far too copious to be absorbed by the latter. For, not to mention the immense evolutions of carbonic acid which are consequent upon every eruption of Vesuvius, and many other volcanoes, its quiet and peaceful exhalation is a phenomenon of very frequent occurrence in many different parts of the globe.

At Franzensbad, near Eger in Bohemia, the Poltersbrunn discharges a large quantity of the acid mixed with a small proportion (about 0.01) of sulphureted hydrogen<sup>3</sup>. The marsh behind the baths of Marienbad also

<sup>1</sup> In all these instances, the carbonic acid was obtained by boiling, which expels not only the acid which is in an uncombined state in the natural water, but also the excess, which goes to convert the carbonates of acidulous waters into bicarbonates.

<sup>2</sup> *Annales de Chim. et de Physique*, xix. 25.—<sup>3</sup> *Osann u. Trommsdorff*, Kaiser Franzensbad, p. 129. The annual amount is estimated at the enormous quantity of 1,102,400 cubic feet.

discharges at every point copious streams of the gas. At Karlsbad it issues in such quantities through the fissures of the great tufaceous vault on which the town is built, that the cellars of the houses in the lower part of the town are completely deserted. Bischof and Nöggerath have described<sup>1</sup> several carbonic acid springs situate in the basin of the Rhine; there is one called Brudelkreis, near the extinct volcano of Gerolstein, in the Eifel, on the right bank of the river Ryll; another called the Wallerborn, is found in the district of Hetzerath, near Triers, on the outer margin of the basin-shaped hills of the Lake of Laach. Near Ems, the so-called *sulphur-hole*, on the left bank of the Lahn, emits a large quantity of the gas, which also issues from several situations in the bed of the river itself. The Ragozi well at Kissingen in Wurzburg, also discharges much carbonic acid (estimated by Pickel at 110 to 170 cubic inches in a minute). Several of the same description are also found in central France: I need only cite the *Puits de la Poule* near Neyrac, in the Vivarais, and the numerous fissures in the lava stream, which extends from Clermont to Royat in Auvergne. I need scarcely add to these the well known *Dünsthöhle*, near Pymont, and the *Grotto del Cane*, near Naples. And very recently, Mr Loudon has given a description of the singular phenomenon of the *Gueno Upas*, or Poisoned Valley, in the Island of Java; the mephitic exhalations of which have not been chemically examined; but from the effects they produce on animal life being identical with those of the Grotto del Cane, doubtless are nothing else than an immense accumulation of carbonic acid<sup>2</sup>. Of the same nature is also, in all probability, the pestiferous exhalations of Alexander's Cave, near Tabriz, in Persia, which are limited to a shallow stratum near the bottom of the cave<sup>3</sup>.

2. *Sulphurous Acid Gas* and *Sulphuric Acid*.—The former is generally emitted in the state of vapour, form-

<sup>1</sup> Schweigger's Journ. N. S. xiii. 28.—<sup>2</sup> Edin. New Phil. Journ. No. 23. Jan. 1832.—<sup>3</sup> Athenæum, No. 221. Jan. 21. 1832. p. 51.

ed by the combustion of sulphur from the crevices and fumaroles among congealed masses of lava. It is a constant product of the lavas of Vesuvius and Etna, according to Monticelli and Covelli; and of many of the Italian solfataras, such as the Grottoes of Santa Fiora, in the Sienese. Also in the Islands of Stromboli, and Bourbon; and Raffles<sup>1</sup> describes a plain at Cheribon, in the north-east of Java, 100 yards in diameter, which emits sulphurous vapours at every point.

Sulphuric acid is equally common in many of the grottoes of Italy; Baldassari mentions its occurrence in that of Zoccolino in Tuscany. Dolomieu found it in a pool in Etna; and Tournefort in the Island of Milo. But the most remarkable instance is the river which issues highly impregnated with sulphuric acid from the crater of Mont Ida in Java<sup>2</sup>; sulphurous acid vapours here issue from all the fissures in the vicinity of the mountain. The observations of Humboldt have also furnished the interesting example of the River Pusambio, or Rio Vinagre, and adjoining hot springs in the Andes of Popayan, in South America, which contains 11.20 of sulphuric acid<sup>3</sup>; the same illustrious traveller found a crust of sulphur lining the fissures of the Volcano of Purace, which he has no doubt was formed by sulphurous acid exhalations rising from its interior; the only gases which he was able to discover by actual experiment, were muriatic acid, and sulphuretted hydrogen.

Another form in which sulphuric acid occurs, is as an excess in waters of a very different class,—those which contain a large dose of the sulphates of iron and alumina. Thus, Dr Thomson found the strong aluminous chaly-

<sup>1</sup> History of Java, 1817, i. 23.

<sup>2</sup> This river, which is remarkable for its destructive effects on the fish and vegetation, was analyzed by Vauquelin, and found to contain besides sulphuric acid, muriatic acid, sulphate of alumina, a small quantity of the sulphates of lime and iron, and traces of non-oxidized sulphur.

<sup>3</sup> Annales de Chim. et Phys. xxvii. 13. M. Rivero, in his analysis of this water, found the sulphuric acid associated with muriatic acid in the proportion of 1.909; Alumina 2.491; Lime 1.661; with traces of iron.



beate of Moffat in this country, to contain 0·743 of the acid in excess.

3. *Muriatic Acid Gas*—follows nearly the same laws, and is found in nearly the same situations, as the preceding. Monticelli and Covelli<sup>1</sup> mention its ejection during the great eruption of Vesuvius in 1822,—that it accompanied the continual rain while it lasted, and that after the eruption it existed in the different fumaroles of the crater and lavas. Etna also disengages muriatic acid vapours. From the observations of Von Humboldt, the hot vapours of Vesuvius, the Peak of Teneriffe and Jorullo in Mexico, when in a state of complete repose, seem at times to contain muriatic acid, although the greater number consist of pure water; besides the two instances of the Pusambio River, and Volcano of Purace above mentioned.

#### GASES.

1. *Sulphuretted Hydrogen*.—When this gas exists in considerable quantity in a mineral water, it is referred to a particular class,—the *Sulphureous*; but like all other springs it is not so much the absolute quantity of sulphuretted hydrogen, which determines a particular water to belong to this class, as its proportion to, and the nature of, the other constituents. It is more commonly associated with the carbonates, muriates, and sulphates of the earths and alkalies, than with metallic salts. In cold springs it is frequently accompanied with carbonic acid: in thermal with azote. In some hot springs which contain as their predominant constituent iron, held in solution by an excess of carbonic acid, an exception has recently been discovered to the general rule, as they have lately been found to contain a minute proportion of the gas: of this description are the thermal waters of Burt-scheid, in the Lower Rhine; and Brandes has recently

<sup>1</sup> Storia dei Fenomeni del Vesuvio, p. 272.



detected it even in the highly acidulated Pyrmont waters <sup>1</sup>.

In all these cases the sulphuretted hydrogen is a constant, if not an invariable, ingredient, independent of all external influence, such as that of season, weather, &c. In other instances its presence is only occasional. Thus, in the thermals of Gastein in Salzburg, traces of it have only been found now and then. In some cold springs it is not an original ingredient, but the product of a partial decomposition of certain sulphates arising from the contact of organic matters, such as particles of straw, chips of wood, &c. Even in common hard waters, which contain a more than ordinary proportion of the sulphate of lime, a minute quantity is sometimes to be traced to this cause. Henry has cited in proof of this the tepid water of Bilazai in France, which is originally quite destitute of sulphuretted hydrogen, but gains a small quantity in its basin by the decomposition of the sulphates in the water from the contact of organic matters <sup>2</sup>. Sulphur is met with in mineral waters in other forms besides this gas. If, then, sulphureous properties were always owing to sulphuretted hydrogen it would be sufficient merely to boil the water to deprive it of its sulphureous character. Many, however, preserve this character even after ebullition, which indicates the presence of a hydro-sulphate, or, as it may be more appropriately termed, a *Hydrothionate*. The most common hydrothionates are those of lime and soda, and it is probable that, if carefully investigated, the sulphureous impregnation of mineral waters would be more frequently owing to these combinations than is generally supposed. Wurzer maintains that he has found the hydrothionate of lime in all the sulphureous waters which he has hitherto examined <sup>3</sup>. And in many of the Caucasian mineral waters, such as those of Kumgara, Catherine's Springs, Paul's Springs, and Peter's Springs, is found the hydrothionate of soda, in a proportion varying from 1.80 to 0.088.

<sup>1</sup> Hufeland u. Osann *Journ. d. Praktisch. Heilk.* lxi. 131.—<sup>2</sup> Kastner's *Archiv.* xi. 493.—<sup>3</sup> *Phys. Chem. Beschreibung der Schwefelquellen zu Nenndorff*, 1815; p. 193.

Westrumb, in 1805, described another combination of sulphur in mineral waters, to which he gave the name of *Fetid Resin* (Stinkharz), which, from the situations in which it is found, is probably formed by a combination of the sulphur derived from iron-pyrites, with petroleum or mineral-pitch.

Sulphureous waters, independently of the grand distinction into thermal and cold, are divisible into those which, on being treated with acids, disengage hydrogen and precipitate sulphur, and those which disengage sulphuretted hydrogen, and precipitate no sulphur.

With these preliminary remarks, I shall now subjoin a tabular view of the quantity of sulphuretted hydrogen in a few of the most celebrated thermal and cold sulphureous water :

## THERMAL.

Bareges in the Pyrenees, . . . .	20.0	Lüdemann.
Cauterets in ditto, . . . .	50.0	Ditto.
St Sauveur in ditto, . . . .	16.6	Ditto.
Schinznach in C. Aargau in Switz., . .	30.11	Peschier.
Aachen in the Lower Rhine, . . . .	45.78	Monheim.
Warmbrunn in Silesia, . . . .	17.17	Osann.
Landeck in county of Glatz, . . . .	14.88	Ditto.
Baden near Vienna, . . . .	11.83	Ditto.

## COLD.

Harrowgate in England, (old well,) . .	5.94	Scudamore <sup>1</sup> .
Moffat in Scotland, . . . .	7.58	Thomson.
Strathpeffer in ditto, (upper well,) . .	9.44	Ditto.
Enghien in France, . . . .	1.60	Longchamps.
Nenndorff in Hesse, . . . .	40.90	Osann.
Winslar in Hanover, . . . .	51.51	Ditto.
Eilsen in Lippe, . . . .	27.21	Ditto.
Meinberg in ditto, . . . .	30.91	Ditto.
Weilbach in Nassau, . . . .	22.32	Ditto <sup>2</sup> .
Berka in Thuringia, . . . .	20.60	Ditto.
Bocklet in Franconia, . . . .	17.17	Ditto.
Doberan in Mecklenburg, . . . .	18.20	Ditto.
Bentheim in Germany, . . . .	15.45	Ditto.
Sironabad in Hesse, . . . .	2.63	Büchner.
Dinkhold in Nassau, . . . .	8.6	Kolb.

<sup>1</sup> I have not admitted the waters of Cheltenham into this list, in consequence of the extreme inconstancy of the sulphureous impregnation. Other reasons, however, render it very doubtful if any of the analyses of some of the recent springs represent their *natural* composition.

<sup>2</sup> 30.9 Creve, (Stifts Nassau, p. 577).

2. *Hydrogen*.—This highly inflammable and fugitive gas could hardly be classed among the constituents of mineral waters, were it not for its intimate connexion with the former. Prodigious evolutions of this gas from the bowels of the earth, are well known to be the constant concomitants of volcanic activity. But in many parts of Italy, as at Cumæ and Baiæ, it is discharged in continued and independent streams. The hydrogenated exhalations of the Pietra Mala in the Apennines, and in the mountains of Cumanacoa in South America, both issue from fetid limestone (mountain). And what is still more to our present purpose, Breislak<sup>1</sup> relates the singular fact of the existence of a sulphureous spring in Campania, which is subject to periodical droughts, at which times pure hydrogen is disengaged from its basin with inconceivable impetuosity, thus affording as it were an analysis by Nature herself, of her secret operations in the production of sulphureous springs<sup>2</sup>.

4. *Azote*.—This gas, distinguished principally by its negative characters, has lately been found to exist in a large proportion of mineral waters. In many cold springs, however, where a minute quantity is associated with carbonic acid and oxygen, it is probably to be regarded more as derived from the intermixture of atmospheric air than as an original product of the earth's interior. But in other instances, where it issues in copious bubbles from the rocky bottoms of the basins of mineral waters, as at the Steinbad in Teplitz, it is certainly to be viewed as an independent constituent of mineral waters. Its quantity is generally very inconsiderable when compared either with sulphuretted hydrogen

<sup>1</sup> Voyage en Campanie.

<sup>2</sup> I need not remind my reader that these inflammable gaseous springs were the bodies of the fabulous rivers of Cocytus and Phlegethon in the district of Pateoli in Italy; and have in more modern times suggested some of the finest conceptions of the poet. Thus, Tasso in *Gerusalemme Liberata*, cant. iv. st. 8:

“ Qual i fiumi sulphurei et infiammati  
Escondi Mongibello, e'l puzzo e'l tuono:  
Tal della fera boeca i neri fiati  
Tale il fetone e le faville sono !”



or carbonic acid ; but it is far more abundant in thermal than in cold mineral waters, in the former of which it seems frequently in a manner to replace the carbonic acid : from it, however, it is at first sight distinguished by the smaller size and more globular form of the bubbles in which it is disengaged from the water. Its cohesion to the water is very small, as it is one of the first gases expelled on the application of heat <sup>1</sup>.

Azote was first discovered in this country by Dr Priestley, in the Bath waters in 1775. The most striking example, however, is the Buxton water, where it is almost the sole gaseous constituent, being mixed with an inconsiderable proportion of carbonic acid ; its quantity, according to the most recent experiments of Scudamore, is 2.01. Tunbridge Wells contain, according to the same author, 1.19 <sup>2</sup> ; Harrowgate, about 1.25. It constitutes 95 per cent. of the gas which bubbles up in the basin of the Bath waters <sup>3</sup>. The sulphureous spring at Holbeck, near Leeds, contains 1.64 <sup>4</sup>. More recently, Professor Daubeny has detected it in the thermals of Bakewell, and Stony Middleton in Derbyshire, and of Taafe's Well in South Wales <sup>5</sup>.

On the continent of Europe, Hermbstädt found the sulphureous waters of Doberan to contain 28.16, mixed with some carburetted hydrogen ; and those of Nenndorf 20.61. The Porla acidulous spring on the borders of the provinces of Nerika and Westmannland in Sweden, discharges copious bubbles of a gas, which was found by Berzelius <sup>6</sup> to consist of 7 parts of azote, 1 part carbonic acid, and a minute quantity of carburetted hydrogen. The acidulous springs of Nocera, in the Papal dominions, contain, according to Morichini, 5.84 of gaseous matters, 3.26 of which are azote, the rest oxygen and carbonic acid, in the proportion of 1.83 and 0.75. Besides, it is

<sup>1</sup> Saunders, u. s. p. 35.

<sup>2</sup> The excess above what is necessary to be combined with the oxygen in the proportions of atmospheric air.

<sup>3</sup> *Priestley's Exper. and Observ. on Air*, 1775, ii. 225.—<sup>4</sup> *Phil. Mag.* i. 248.—<sup>5</sup> *Edin. New Phil. Journ.* Jan. 1832, p. 65.—<sup>6</sup> *Lehrbuch, der Chemie*, ii. 1824, p. 777.



found in the thermal waters of Aachen, Baden in Austria, Baresges, Cauterets, St Sauveur, Aix, Leuk, Wiesbaden 0.31, Ems 0.21, Schlangenbad 0.069, Karlsbad, Teplitz, Neris, Bourbonne les Bains, Luxueil, Balaruc, Avene, Mont d'Or, Chaudes Aigues, Vichy. It is evolved from many of the thermals of the Alps nearly quite pure, as at St Gervais, Courmayeur, St Didier, Bonneval: in only the last of these is it associated with any carbonic acid (about 12 per cent.). At Castellamare in the Bay of Naples. In those of Monghyr in India<sup>1</sup>, of Onoto and Mariara in South America<sup>2</sup>. In the cold springs of Eilsen, Pyrmont, Gleissen, &c., and the mineral waters of Rensselaer in the State of New York, United States, where it is discharged in copious bubbles from the gravelly bottom of the basin<sup>3</sup>.

4. *Carburetted Hydrogen*.—This gas is often associated with the preceding; but it is much more modified by the local situation of springs, being generally most abundant when they issue forth in the vicinity of beds of coal, of peat, or of animal and vegetable matters in a state of decomposition and fermentation. Accordingly, it is not an unfrequent concomitant of those superficial ferruginous infiltrations which flow from the slates, bituminous shales and argillaceous sandstones of coal districts. Its quantity is always trifling. At Harrowgate it is in nearly equal proportion to the azote, about 1.25. The Augustusbad chalybeate in Saxony, contains, according to Ficinus, 2.44; it is present also in the sulphureous waters of Eilsen and Nenndorf. In Italy it accompanies many of the hydrogenated and sulphuretted gaseous springs for which this country is so remarkable.

5. *Oxygen Gas and Atmospheric Air*.—These can hardly be considered as ingredients peculiar to mineral waters, being common both to them and simple terrestrial and atmospheric waters; indeed, their quantity in the latter

<sup>1</sup> Asiatic Journ. No. 85, p. 58.—<sup>2</sup> Annales de Chim. et Phys. 1823, p. 272.—<sup>3</sup> Eaton's Geolog. Survey of Rensselaer County, 1822, p. 29.

is generally the most considerable. They could not, however, be omitted in the present arrangement, as they exist in many mineral springs. Oxygen being incompatible with sulphuretted hydrogen and iron, whenever it is indicated as existing in sulphureous or chalybeate waters, such as Holbeck, Nenndorf, Neris, and Tunbridge, we must consider it as neutralised by azote in the proportions to form atmospheric air; but in acidulous springs, such as those of Nocera, Valdieri, and many others in Italy, it may be considered as an independent constituent. Atmospheric air is universal, in a certain proportion, in almost all waters; and Döbereiner even asserts that he has found it in distilled water, which has merely been exposed to the air<sup>1</sup>. The mineral water of Pitcaithly in this country, contains 1.73; of Tunbridge 1.08; of Bristol hot-well 1.30.

#### VEGETO-ANIMAL MATTER.

THE quantity of the organic ingredients of springs is always very small, scarcely ever amounting to one part in 10,000 of water. In some cases, its origin is of easy explanation, being derived from beds of coal, petroleum, fossil vegetable or animal remains, or other bituminous substances situate in the route of a mineral water through its subterranean channels towards the surface. But that highly azotized principle, so frequent in many hot-springs, is utterly inexplicable by this cause, as they are found to emerge from granite and crystalline schistous rocks, as in the Pyrenees, or from the ancient trachytes, products of former volcanic operations, as in central France, matrices utterly destitute of all vestiges of organic life.

These vegeto-animal substances may be very naturally divided into three kinds or species, distinguished both by their external characters, and, if I may so express myself, their hydrographical position.

<sup>1</sup> Über das Chemische Constitution der Mineralwasser, 1821, p. 6-11.

1. *Humus-extractive*.—This has been principally found in cold springs of the saline, chalybeate, and acidulous divisions. Thus, Berzelius found it in the proportion of 0.08 in the Karlsbad acidulous spring; in the Königswart drinking spring 0.205, the bathing spring 0.057. Steinmann found in the Kreuzbrunnen at Marienbad 0.80, the Karoline Wells 0.99. Braconnot found the solid matters of the thermal waters of Luxueil to contain 4 per cent. of a substance which he has denominated *Ulm*, and which may probably be referred to this head <sup>1</sup>.

2. *Resinous Extractive*.—This is most common in cold sulphureous and chalybeate springs. It is closely allied to mineral resin, if it be really a distinct substance. It is cited as occurring in many of the mineral waters of Italy <sup>2</sup> and Hungary. John has found it in those of Gleissen in Brandenburg, and Hermbstädt at Muskau.

3. *Baregine or Animal Extractive* <sup>3</sup>.—Certainly the most interesting of the organic matters of mineral waters. It is almost peculiar to thermal waters, and very generally occurs in those of a very elevated temperature.

Scheuchzer, about the beginning of last century, was the first who recognised it as a distinct substance, characterized by its unctuous and resinous qualities. Its true animal nature was, however, not clearly made out till Lemonnier, in 1747, described its occurrence in the waters of Bareges. Since which, its characters have been thoroughly investigated by Longchamps, Vauquelin, Chaptal, Anglada, &c.

The most precise physical and chemical description of

<sup>1</sup> Annales de Chim. et Phys. xviii. 225.—<sup>2</sup> Paganini, Notizia Compendiata di tutte le acque Minerali et bagni d'Italia, 1827, p. 47.

<sup>3</sup> I have adopted the denomination given it by Longchamps, derived from one of its principal localities, the hot sulphureous springs of Bareges in the Pyrenees. Gimbernath (Bibliothèque Universelle, xi. 150,) gives it the name of *Zoogen*. Monheim calls it *Theiothermin*, from its frequent occurrence in hot sulphureous waters. Lastly, Anglada has given it the appellation of *Glairine*.



this substance has perhaps been given by Monheim<sup>1</sup>, which I shall make no apology for shortly stating to the reader. It is an unctuous substance of a greyish-white colour. When cold, it has little smell or taste. It is little soluble in cold water, more so in warm, and the hot solution has very much the smell and appearance of thin beef tea. The residuum, after evaporation to dryness, has a corneous aspect, and is semi-transparent. When thrown on burning coals, it neither melts nor bubbles up, but burns away with a strong animal odour, leaving behind a rather refractory residuum. When subjected to destructive distillation, it yields carbonate of ammonia, azote, carburetted hydrogen, and carbonic acid; if before distillation it has not been wholly freed from the sulphate of soda with which it has been associated in the mineral water, we obtain in addition, traces of sulphur and sulphuretted hydrogen. It is soluble in caustic alkalis, with which it forms a soap. Less soluble in the carbonated alkalis, but more so than in pure water. Strong sulphuric, muriatic and acetic acids precipitate a concentrated aqueous solution, but the precipitate is re-dissolved by frequent agitation with additional water. Diluted nitric acid disengages azote, and it behaves entirely like an animal substance. It is insoluble in ether and alcohol, both of which precipitate it from its aqueous solution. It is precipitated by a solution of the muriate of gold, and after twelve hours the mixture is covered with a thin pellicle of metallic gold. Nitrate of silver produces at first a scarcely perceptible cloud, but after a time there falls a light, flocculent, brownish deposit. Acetate of lead at first causes a very slight white cloud, which is succeeded after a time by a flocculent, whitish precipitate. No change is produced in its solution by corrosive sublimate. An aqueous infusion of nutgalls produces a distinct turbidity, and after a time, a flocculent, brownish deposit. But M. Monheim observes, that one of its most characteristic features is,

<sup>1</sup> Die Heilquellen v. Aachen, Burtscheid, Spaa, Malmedy, u. Heilstein, 1829, p. 248.



a very long exemption from putridity when exposed to all the necessary conditions of air, caloric, and humidity. From these characters, it will be seen, that it exactly agrees neither with gelatin, tannin, nor mucus; but certainly resembles the latter more than the other two.

It has hitherto been chiefly found in thermal sulphureous springs. It possesses all the preceding characters in those of Aix-la-Chapelle and Burtscheid; Baden in Austria, and Baden in Switzerland; besides Bareges, Bagnols, d'Aix, &c.<sup>1</sup> An animal matter closely resembling the above has been detected by Longchamps<sup>2</sup> and Vauquelin<sup>3</sup> in the springs of Vichy; and has been found also in Plombieres, Bourbon l'Archambault, Dax<sup>4</sup>; Aix in Provence, Mont d'Or, and Sylvanes<sup>5</sup>; Kastner has detected it in Wiesbaden<sup>6</sup>; and Ambrozzi<sup>7</sup> found, in the hot springs in the town of Teplitz, 0.06 of a substance which he simply terms extractive;—all thermal waters destitute of sulphuretted hydrogen. Gimbernat has found the substance, which he has denominated Zoogen, in the thermal vapours which rise from many springs, from Vesuvius, and the solfatara of Pozzuoli.

Animal matters are much less common in cold springs. Vauquelin and Thenard found a *Matiere grasse* in the water of Provins near Paris<sup>8</sup>; and baregine exists in a spring near Bex. Scherer also describes an animal substance in many of the springs of south Russia.

A few words upon the origin of this singular substance, so highly interesting to the chemist, but more especially to the geognost, and which may perhaps prove not altogether unworthy of the attention of the scientific physician, will not be here altogether out of place. Berthier<sup>9</sup> has advanced an opinion, which cannot be admitted when we attentively consider all the circumstances of its position, viz. that it is not an original and independent constituent of thermal waters, but is merely pro-

<sup>1</sup> Alibert, *Precis*, p. 217.—<sup>2</sup> *Analyse des Eaux Minerales et Thermales de Vichy*, p. 83.—<sup>3</sup> *Annales de Chimie*, xxviii. 98.—<sup>4</sup> Patis-  
sier, u. s. pp. 330, 442, 497.—<sup>5</sup> Alibert, u. s. pp. 111, 119, 217.—  
<sup>6</sup> *Archiv. f. d. ges. Naturlehre*, xiii. 418, 419.—<sup>7</sup> *Physikalisch-Chem.*  
*Untersuchung der Min. quell. zu Teplitz*, 1797.—<sup>8</sup> Patis-  
sier u. s. p. 369.—<sup>9</sup> *Journal des Mines*, vi. 215.

duced by the action of the air and light on their emergence to the surface. Fabroni <sup>1</sup> supposes that it may be derived from the percolation and lixiviation, as it were, of fossil bones by the mineral water in its route through the earth's interior. As I have already observed, whatever use we can make of this to explain the origin of resinous and humus-extractive, it is totally incapable of resolving the problem of the origin of baregine, which, if not exclusively, yet, in by far the majority of instances, occurs in springs which issue from granite, mica-schist, trachyte, &c. which are devoid of all traces not only of animal remains, but of the very elements of organic compounds. In the valuable treatise above cited, Monheim has quoted a singular experiment <sup>2</sup> of Döbereiner's, which, if not explaining, is extremely pertinent to the present question. Upon passing watery vapour over red hot coals, contained in an iron tube, in greater quantity than what could be decomposed, he obtained, besides carbonic acid, carbonic oxide, and carburetted hydrogen, a *gelatinous* substance, in such quantity as to close up the tube several times in succession: this substance was very soluble in water, and possessed many of the physical and chemical properties of tallow.

## SECTION II.

### AMOUNT OF THE FOREIGN INGREDIENTS OF MINERAL SPRINGS.

1. *Specific Gravity*.—This, the most important of the characters of mineral waters, has a very extensive range. In a few, it is even less than that of distilled water. However simple at first sight as may appear the determination of the specific gravity of a water, many precautions require to be attended to, a ne-

<sup>1</sup> Giornale di Fisica, 1828, x. 213-227.—<sup>2</sup> Detailed in Gilbert's Annalen der Physik, lviii. 210-213.

glect of which often leads to very fallacious results, and is one of the chief causes of the discrepancies in the indications of different observers. Many springs which are strongly impregnated with gaseous matters, even upon a very slight elevation of temperature, not more than to  $60^{\circ}$  Fahr., disengage a number of minute bubbles, which remain suspended in the water, or adhere to the sides of the containing vessel, and tend materially to lessen its true specific gravity. Sulphuretted hydrogen being not only much lighter, but also retained by a much weaker cohesion in union with the water, than carbonic acid, the errors arising from this cause are more considerable in sulphureous than in acidulated waters, although in the latter they are not altogether imperceptible. Kirwan recommends the specific gravity of acidulous springs never to be taken at higher temperatures than  $50^{\circ}$  F.<sup>1</sup> That of thermal springs ought, for the same reasons, to be ascertained after having cooled down to the ordinary atmospheric temperature. The waters of Selters, well known to be highly charged with carbonic acid, afford a strong proof of the power of even a very small increase of temperature materially raising the specific gravity of acidulous waters. Bergman found it at  $59^{\circ}$  F. to be 1002.7; and Brisson, at  $61^{\circ}$  F., raised to 1003.5.

Another cause will exactly reverse the effects of the preceding, and tend to increase the true weight of a natural water, viz. its frequent and violent agitation, either in its natural receptacle, or by a long land-carriage to the laboratory of the experimenter. This will disengage no small proportion of the gas held naturally in solution, particularly if it approach the point of saturation, and which ought certainly to go toward constituting its natural specific gravity on its emergence from the bowels of the earth.

Kirwan has proposed an ingenious formula for deducing the quantity of salt in a saline solution, from its specific gravity. It consists in simply subtracting 1000

<sup>1</sup> On the Analysis of Mineral Waters, 1799, p. 144



from the specific gravity expressed in whole numbers, and multiplying the product into 1.4, or, more briefly,

Sp. gr. — 1000 = Diff. ; and Diff.  $\times$  1.4 = Quantity of Salt.

He has found the error arising from this rule never to exceed 1 or 2 per cent. on comparing the specific gravity and weights of artificial solutions of common salt, nitrate of potass, sulphate of soda, carbonate of soda, sulphates of iron, copper and zinc, and proposes to extend it to mineral waters. It gives the weight of the salts in their dry state. The same correspondence, however, is not found on comparing together the specific gravities and quantity of saline constituents of many springs ; but as the deviations are most considerable in those which seem to have been analyzed with fewest precautions, and in which the foregoing observations have been least attended to, we may suppose the errors more owing to a faulty specific gravity than to the defects of the formula. As it is, however, in consequence of this nonconformity, it cannot be trusted to as giving the *exact* impregnation of a spring, but only an *approximation*. For example, the specific gravity of the saline drinking spring at Pyrmont was found by Westrumb 1011; its saline contents are 15.34 in 1000 of water. Now,  $1011 - 1000 = 11$ , and  $11 \times 1.4 = 16.1$ , giving a difference of 1.24 parts in 1000 between the calculated and actual impregnation. Again, the specific gravity of the Bath waters is 1002, their solid contents 1.9: Now,  $1002 - 1000 = 2$ , and  $2 \times 1.4 = 2.8$ , giving an excess of 0.9. Karlsbad Sprudel, sp. gr. 1005, solid contents 5.4: Now,  $1005 - 1000 = 5$ , and  $5 \times 1.4 = 7.0$ , giving an excess of 1.6. Pfeffers in Switzerland, sp. gr. 1004, solid contents 0.4: Now,  $1004 - 1000 = 4$ , and  $4 \times 1.4 = 5.6$ , giving an excess of 5.2.

Lastly, we can only attribute to an error in ascertaining the correct specific gravity, its supposed identity in two springs of very different strength. This is the case with the alkaline springs of Wildbad in Wurtemberg, and the purging waters of Pfeffers in Switzerland, both of which are indicated as possessing the same specific



gravity, viz. 1004, while the cold contents of the latter are almost three times as much as the former.

I shall now give a tabular view of the specific gravities of a few of the more remarkable thermal and cold springs :

## THERMAL.

Bath in England (King's and Hot Baths),	1002.38	Falconer.
Ditto (Cross Bath), . . . . .	1001.8	Ditto.
Buxton in England, . . . . .	1000.60	Scudamore <sup>1</sup> .
Bristol Hot Well in ditto, . . . . .	1000.77	Saunders.
Matlock in ditto, . . . . .	1000.3	Scudamore.
Aix in Savoy, . . . . .	1001.0	Bertini.
St Gervais in ditto, . . . . .	1004.3	De la Rive.
Pfeffers in Switzerland, . . . . .	1004.0	Capeller.
Wildbad in Würtemberg, . . . . .	1004.0	Kerner.
Wiesbaden in Nassau, . . . . .	1006.30	Kastner.
Karlsbad Sprudel in Bohemia, . . . . .	1004.97	Berzelius.
Valdieri in Piedmont, . . . . .	1000.0	Giobert.
Ems in Nassau, . . . . .	1003.55	Kastner.
Schlangenbad in ditto, . . . . .	1000.55	Ditto.
Maschuka in the Caucasus, . . . . .	1004.0	Hermann.
Eisenberg in ditto, . . . . .	1002.5	Ditto.
Kumgara in ditto, . . . . .	1001.25	Ditto.
Paulsquellen in ditto, . . . . .	1001.5	Ditto.
Katherinen and Petersquellen in ditto, . . . . .	1001.0	Ditto.

## COLD.

Tunbridge Wells in England, . . . . .	1000.70	Scudamore.
Harrowgate in ditto (old well), . . . . .	1010.3	Ditto <sup>2</sup> .
Cheltenham in ditto (old well), . . . . .	1009.1	Ditto.
Leamington in ditto, . . . . .	1011.9	Ditto.
Malvern in ditto, . . . . .	1000.2	Ditto.
Isle of Wight chalybeate, . . . . .	1007.5	Marcet.
Moffat in Scotland (sulphureous), . . . . .	1002.55	Thomson.
Hartfell Spa in ditto, . . . . .	1000.7	Ditto.
Ditto (aluminous chalybeate) . . . . .	1009.65	Ditto.
Strathpfeffer in ditto, . . . . .	1001.91	Ditto.
Dunblane in ditto (north spring), . . . . .	1004.75	Murray.
Schulz in Switzerland, . . . . .	1003.0	Capeller.
Pymont in Waldeck (acidulous), . . . . .	1001.0	Brandes.
Ditto (saline), . . . . .	1013.3	Westrumb.
Geilnau on the Lahn, . . . . .	1004.0	Bischof.
Selters in Nassau (Nieder), . . . . .	1003.69	Westrumb.
Nocera in Papal dominions (acidulous), . . . . .	996.0	Morichini.
Envie, near Turin, . . . . .	1000.0	Kirwan.
Salzhausen in Hesse (brine spring), . . . . .	1008.5	Schmidt.

<sup>1</sup> At 60° immediately from the basin, at 77°, it is 999.0.

<sup>2</sup> Stated by Dr Garnett at 1006.4.

Marienfels in Nassau,	1001.0	Kastner.
Langenschwalbach in ditto (Stahlbrunn),	1001.0	Gaertner.
Weilbach in ditto,	1001.52	Creve.
Kislawodsk in the Caucasus,	1003.0	Hermann.

I shall subjoin, for the sake of comparison :

Sea-water, according to Gay-Lussac,	1028.6
Ditto, according to Dr J. Davy,	1026.4 <sup>1</sup>
Water of the Dead Sea, by Lavoisier,	1240.3
Ditto, by Gay-Lussac,	1228.3
Ditto, by Marcet,	1211.0
Alumino-ferruginous infiltration in the iron-mines of Vicar's Bridge, by Connell,	1048.93
Water saturated with carbonic acid, by Bergmann,	1001.5

2. *Amount of Solid Matters.*—It was long thought, that by nothing were mineral springs so well distinguished from other terrestrial waters, than by their much larger impregnation of solid matters. It is now however known, that many which possess very active chemical and medicinal properties, are purer than some common drinking waters. There is in fact an insensible transition from the strongest mineral springs to the purest atmospheric waters. No precise definition can therefore be given of this portion of that great mass of aqueous fluid which envelopes and penetrates the terraqueous globe in every direction, linked, on the one hand, with the great mass of the ocean itself, and, on the other, with those dewy exhalations which distil on the arid deserts of Arabia. We cannot, I say, strictly define mineral waters, when viewed in connexion with the general physics of the earth, however they may be denominated as therapeutical agents, to be “those natural springs which issue from the bowels of the earth charged with principles to which experience gives medical virtues <sup>2</sup>.”

The springs richest in foreign matters, are those in which the muriates and sulphates predominate: these

<sup>1</sup> Phil. Trans. 1817, p. 275. This is the mean of thirty-six observations, made during a voyage to Ceylon; the highest N. Lat. was 48°, in Long. 10° W.; the highest S. Lat. was 36°, in Long. 34° W. The extremes were 1027.7 and 1025.1.

<sup>2</sup> Alibert *Precis*, p. 1.

very commonly contain from 10 to 40 parts in 10,000 of water, occasionally 60 or 70, and in a few it amounts even to upwards of 100. Others never amount to 10, in most cases much less: these are principally of the thermal class, or, if cold, chalybeate, sulphureous, or acidulous, and generally those strongly impregnated with gaseous matters.

Agreeably to custom, I shall now present a tabular view of the solid impregnation of a few springs, premising, that the residuum is, in every case, in its dry state, deprived of its water of crystallization by having been heated to  $212^{\circ}$ , but still retaining its combined carbonic acid.

## THERMAL.

Bath in England, . . . . .	20.53	Philips.
Buxton in ditto, . . . . .	2.70	Pearson.
Bristol in ditto, . . . . .	8.19	Carrick.
Mont d'Or in France, . . . . .	13.39	Berthier.
St Nectaire in ditto, . . . . .	53.94	Ditto.
Vichy in ditto, . . . . .	42.75	Ditto.
Chaudes Aigues in ditto, . . . . .	9.96	Ditto.
Bareges in ditto, . . . . .	1.15	Lüdemann.
Cauterets in ditto (Cæsar spring), . . . . .	30.80	Ditto.
St Sauveur in ditto, . . . . .	45.72	Ditto.
Sylvanes in ditto, . . . . .	6.35	Osann.
Plombieres in ditto, . . . . .	8.14	Alibert.
Karlsbad Sprudel in Bohemia, . . . . .	54.59	Berzelius.
Teplitz Steinbad in ditto, . . . . .	6.24	Ditto, 1821 <sup>1</sup> .
Wiesbaden in Nassau, . . . . .	84.15	Kastner.
Ems in Nassau (Kränchesquelle) . . . . .	41.02	Ditto.
Wildbad in Würtemberg, . . . . .	1.36	Kerner.
Annaberg in Saxony, . . . . .	4.07	Kühn.
Landeck in County of Glatz, . . . . .	4.07	Osann.
Schlangenbad in Nassau, . . . . .	8.14	Kastner.
Gastein in Salzburg, . . . . .	3.39	Trommsdorff.
Pfeffers in Switzerland, . . . . .	3.80	Capeller.
Bormio in ditto, . . . . .	5.52	Demagri.
Gurgitello in Ischia, . . . . .	74.03	Giudice.
San Restituta in ditto, . . . . .	94.44	Ditto.
Olmitello in ditto, . . . . .	24.42	Ditto.
Carratraca in Spain (temp. $66^{\circ}$ ), . . . . .	5.75	Alibert.
Maschuka in the Caucasus (Michaeli spr.), . . . . .	42.43	Hermann.
Eisenberg in ditto, . . . . .	23.99	Ditto.
Kumgara in ditto, . . . . .	15.73	Ditto.
Paulsquellen in ditto, . . . . .	14.02	Ditto.
Petersquellen in ditto, . . . . .	14.59	Ditto.
Catherinenquellen in ditto, . . . . .	10.17	Ditto.

<sup>1</sup> Ambrozzi, in 1797, states it at 21.37, which, even excluding the water of crystallization, is more than double the quantity obtained by the Swedish chemist.

## COLD.

England, Tunbridge chalybeate, . . .	1.32	Scudamore.
Harrowgate, sulphureous saline (old well), . . .	145.4	Ditto, 1819 <sup>1</sup> .
Harrowgate saline chalybeate, . . .	59.06	Ditto.
Cheltenham, saline (old well), . . .	111.6	Scudamore.
Leamington, (Royal Pump), saline, . . .	153.9	Thomson.
Ditto, ditto, sulphureous, . . .	51.83	Scudamore.
Gloucester, sulphureous saline, . . .	96.23	Daubeny.
Llandrindod, Radnorshire, saline, . . .	35.83	Ditto.
Malvern (St Anne's Well), alkaline, . . .	10.12	Philip.
Isle of Wight, aluminous chalyb. . .	147.0	Marcet <sup>2</sup> .
Ashby-de-la-Zouch, Leicestershire, brine spring, . . .	205.6	Daubeny.
Northwich, Cheshire, brine spr. . .	1938.0	Henry.
Droitwich, Worcestershire, brine spring, . . .	1995.0	Daubeny.
Shirleywich, Staffordshire, brine spring, . . .	1774.0	Ditto.
Epsom, saline, . . .	54.86	Lucas.
Scarborough, saline, . . .	43.81	Short.
Beulah, Surrey, saline, . . .	120.3	Faraday and Hume.
Scotland, Moffat, sulphureous, . . .	30.03	Thomson.
Hartfell, chalybeate saline, . . .	9.95	Ditto.
Ditto, aluminous chalybeate, . . .	101.3	Ditto.
Strathpfeffer (upper well), sulphureous, . . .	19.74	Ditto.
Dunblane (north spring), saline, . . .	63.21	Murray.
Pitcaithly, saline, . . .	46.95	Ditto.
Airthrey, saline (No. 1.), . . .	127.1	Thomson.
Ditto, ditto, (No. 4.), . . .	39.57	Ditto.
Innerleithen, saline (strongest) . . .	41.57	Fyfe.
Vicar's Bridge, aluminous chalyb. . .	563.1	Connell.
France, Vals, Dep. de l'Ardeche, alkaline, . . .	61.17	Berthier.
Enghien near Paris, chalyb. sulph. . .	69.46	Longchamps.
Germany, Püllna in Bohemia, saline, . . .	247.0	Pleischl.
Saidchütz in ditto, saline, . . .	217.2	Steinmann.
Seidlitz in ditto, saline, . . .	171.0	Neumann.
Karlsbad in ditto, acidulous, . . .	1.42	Berzelius <sup>3</sup> .
Königswart in ditto (drinking spring), alkaline chalyb. . .	8.90	Ditto.
Ditto, (acidulous spring), . . .	1.53	Ditto.
Franzensbad in ditto, alkaline chalybeate, . . .	54.84	Ditto.
Marienbad in ditto, alkaline purging, . . .	59.85	Steinmann.
Bilin in ditto, alkaline, . . .	57.46	Reuss <sup>4</sup> .

<sup>1</sup> Garnett, in 1794, obtained 129.3.<sup>2</sup> Includes the water of crystallization.<sup>3</sup> Stated by Lampadius, who analyzed it at Freyberg, at 3.12.<sup>4</sup> Probably includes the water of crystallization.



Germany, Geilnau in Nassau, acidulous,	14.65	Bischof.
Fachingen in ditto, alkaline, .	32.98	Ditto.
Selters in ditto, acidulous, .	34.59	Ditto.
Dinkhold in ditto, . . . .	35.67	Kolb.
Marienfels in ditto, . . . .	16.71	Kastner.
Soden in ditto, . . . .	32.19	Meyer.
Montabaur in ditto, . . . .	4.40	Jacobi.
Langenschwalbach in ditto, (Weinbrunn), . . . .	8.94	Kastner.
Weilbach in ditto, . . . .	15.01	Creve.
Pyrmont in Waldeck, saline spr.	153.4	Brandes.
Ditto ditto, brine spring,	128.9	Ditto.
Ditto ditto, acidulous spring,	5.05	Ditto.
Spaa, alkaline chalyb. . . .	4.57	Monheim.
Kissingen in Franconia, chalyb. saline, . . . .	111.3	Vogel.
Nenndorff in Hesse, brine spr.	126.2	Wurzer.
Doberan in Mecklenburg, sul- phureous, . . . .	103.1	Hermstädt.
Switzerland, Blumenstein in Bern, chalyb.	8.19	Fueter.
Lochbachbad in ditto, chalyb.	14.88	Osann.
Rolle in Pays de Vaud, chalyb.	4.63	Peschier.
Stachelberg in Glarus, sul- phureous, . . . .	13.71	Kielmayer.
Tarasp in Engaddin, alkaline,	126.2	Capeller.
Limpacherbad in Bern, alka- line, . . . .	1.87	Osann.
St Moritz in the Grisons, aci- dulous, . . . .	13.57	Capeller.
Bernardino in ditto, acidulous,	32.57	Ditto.
Italy, Nocera in Papal territory, acidulous,	2.33	Morichini.
United States, Ballstown, New York, aci- dulous chalybeate, . . . .	106.4	Hosack.
Peru, Antioquia, brine spring, . . . .	2936.0	Boussingault.
Caucasus, Kislawodsk, . . . .	21.88	Hermann.

3. *Amount of Gases.*—They are distinguished by this more than by the former from ordinary terrestrial waters, as these rarely contain any foreign gas, with the exception of a small portion of atmospheric air. Great varieties, however, exist in the degree of gaseous impregnation of different mineral waters, determined principally by their temperature, their concomitant solid matters, and the nature of the gases themselves. I have formerly observed, that, generally speaking, the quantity of gas is inversely as the temperature, although this suffers many modifications, and even exceptions, in the case of some gases. A large dose of the carburetted earths and alkalis generally is associated with, and enables the water to hold in solution a much larger quantity of, car-

bonic acid, than when the sulphates or muriates predominate. When carbonates are not present, the smaller the amount of solid matters the greater the quantity of gaseous constituents. Azote seems to have a particular affinity for, or to be very generally associated with, thermal waters, as carbonic acid is with cold. Sulphuretted hydrogen seems indifferent to thermal or cold springs, its presence being chiefly favoured by a large dose of the sulphates. As before noticed, we must carefully distinguish the case where a large quantity of gas streams through a water from that where it is in intimate chemical solution; for it not unfrequently happens, as in the case of the Karlsbad acidulous spring, that a water disengages a large quantity of superabundant gas, when it is itself very far from the point of saturation; the Bath waters also, although they disengage copious bubbles of a gaseous compound, containing 95 per cent. of azote, do not contain any of this gas in solution.

AMOUNT OF GASES IN SOME OF THE MORE HIGHLY IMPREGNATED WATERS.

Buxton in England (thermal),	. . . . .	2.66	Scudamore.
Tunbridge in ditto,	. . . . .	5.76	Ditto.
Harrowgate in ditto,	. . . . .	12.57	Ditto.
Bristol hot well, in ditto,	. . . . .	3.27	Carriek.
Cheltenham in ditto,	. . . . .	19.72	Fothergill.
Moffat,	. . . . .	8.22	Garnett.
Kilburn, near Moffat?	. . . . .	21.62	Thomson.
Pymont (drinking spring),	. . . . .	171.0	Brandes.
Reinerz in County of Glatz,	. . . . .	156.0	Mogalla.
Franzensbad, Francis' spring,	. . . . .	153.0	Trommsdorff.
Marienbad, Ferdinand's spring,	. . . . .	145.0	Steinmann.
Selters	. . . . .	124.0	Westrumb.
Obersalzbrunnen in Silesia,	. . . . .	130.0	Fischer.
Balaruc in France (thermal),	. . . . .	11.07	Figuier.
Enghien in ditto,	. . . . .	24.31	Longchamps.

4. *Constancy of the Impregnation of Mineral Waters.*—

It is only comparatively of recent date that chemical analyses have attained that degree of exactness which is necessary to institute comparisons upon this point.

The springs which are most remarkable for the uniformity of their composition at different periods, are un-

doubtedly those of the thermal class. Many of these have been known for a period of 2000 years; and although, from the imperfect state of early chemistry, we cannot affirm that they have possessed a perfect identity of composition throughout this long course of years, yet, as far as we can infer from the recitals which the ancient authors have given of their effects, their constitution cannot have materially differed from what it is at present. What Pliny mentions with regard to the springs of Wiesbaden, still holds true in modern times. The effects ascribed 200 years ago by Reudenius and Hillinger to the Bohemian baths, do not differ materially from what are observed now; and Paracelsus, 800 years back, seems to have been equally aware of the virtues of many of the thermal waters of the south of Germany and Switzerland. If these indications of the ancient authors should not be deemed sufficiently exact for the decision of the question, modern chemists have furnished us with facts which are free from any objection. Berzelius, in 1821, found his analysis of the Karlsbad Sprudel to differ in no essential point from that of Becher in 1770, and of the distinguished chemist Klaproth in 1789. There was indeed a difference of about 1 part in 10,000 between the quantity of solid matters obtained by the latter and the Swedish chemist; but this is entirely attributable to their different methods of analysis, not to any change in the composition of the water. We have thus a well established instance of a perfect identity in the composition of a thermal water during a long course of thirty-three years. Some observations, however, it cannot be denied, seem to oppose this uniformity being admitted as a general principle with regard to hot springs. Thus the Steinbad at Teplitz, as I have already hinted at, was found by Berzelius, in 1822, to contain only half the quantity of solid matters found by Ambrozzi in 1797; upon which the former proposes the queries: "Has the Teplitz water, during these twenty-five years, really undergone this important change in its solid impregnation? Are these changes capable of being produced by an unusually dry



state of the weather? Or does the difference entirely depend upon the errors of observation?"<sup>1</sup> It merits, however, being remarked, that Ficinus found striking variations in the quantities both of solid and gaseous matters in the Teplitz springs, drawn at different hours. In our own country a similar uniformity may be observed with regard to the Buxton waters, the quantity of solid matter obtained by Dr Pearson in 1784 agreeing to a single grain (in both 15.0 in a gallon) with that by Scudamore in 1819. The Bath waters are subject to changes, to which we may equally apply the queries instituted by Berzelius with regard to the Teplitz water: the quantities have been successively 22.6<sup>2</sup>, 23.3<sup>3</sup>, 12.2<sup>4</sup>, 15.9<sup>5</sup>, and 19.17<sup>6</sup>.

Some cold springs exhibit also a striking uniformity of impregnation during a long series of years. Bischof<sup>7</sup>, on comparing his analysis of the water of Geilnau with that of Amburger in 1795, has come to the conclusion, that not only the total quantity of solid matters has undergone no change during the space of thirty-three years, but that it is even probable that the relative proportion of the different constituents has continued unaltered. This chemist comes to the same inference with respect to the waters of Fachingen, for the period of seventy-eight years, on comparing his analysis with that of Burggrave in 1747, and of those of Selters for thirty-eight years, since Westrumb's analysis. It is obvious, however, that we can arrive at perfect certainty regarding the unchangeability of the composition of these waters only by an exact analysis repeated for several successive times after intervals of some years between each.

Other cold mineral waters experience changes which can easily be traced to atmospheric causes,—to weather, to the seasons, &c. Westrumb has given us some valuable observations<sup>8</sup> on the changes which the Pyrmont

<sup>1</sup> Berzelius, u. s., p. 93.—<sup>2</sup> Lucas, in 1756.—<sup>3</sup> Charlton, in 1774.—<sup>4</sup> Falconer, in 1790.—<sup>5</sup> Gibbs, in Nicholson's Journal for 1799 and 1800.—<sup>6</sup> Scudamore, in 1819.—<sup>7</sup> Bischof, Die Vulkanisch. Mineral-quell. Deutschlands u. Frankreich, 1826, p. 329.—<sup>8</sup> Physico-chemical description of the Pyrmont waters, p. 17.

waters undergo at different seasons. His experiments were made on the residuum of portions of water drawn in the months of March, June, July and August 1788. He found,—1. That the total quantity of the solid constituents of the Pyrmont waters is almost always the same, varying only from  $23\frac{1}{4}$  to 24 grains in a pound; in the year 1783 he obtained 23.4 grains. 2. In March, the water contained a larger proportion of saline matter and iron, and less sulphate of lime, than in the other three months: this difference was not, however, observed in 1783, which he ascribes to the very equable weather of that year. 3. The constituents are always the same, it is only their quantities which vary: those of the iron, muriates of soda and magnesia, and sulphate of lime, are subject to the fewest changes, which are more remarkable with regard to the lime, the sulphates of soda, and magnesia. It is remarkable that the quantity of one of these substances often increases in the same proportion to the decrease of another. 4. The changes of the weather have very little influence on the carbonic acid, the quantity of which is always nearly the same, but the impregnation is a little greater in east and north-east winds. 5. He found 29 grains of solid matter in the same quantity of water, from which Gmelin, the year before, could only obtain  $11\frac{1}{2}$  grains. Wurzer, who has paid much attention to the effect of atmospheric influences on mineral waters, instituted a comparative analysis of the sulphureous waters of Nenndorff, in the summer of 1814, which was very hot and dry, and that of 1823, which happened to be cloudy and wet. On the latter occasion, the drinking spring contained a much larger proportion of solid matters, and the bathing-spring of sulphuretted hydrogen, in the drinking spring the carbonic acid predominated over the sulphuretted hydrogen, which is not usually the case<sup>1</sup>. Klaproth found the mineral water of Riepoldsau, in the Grand Duchy of Baden, in 1806, to contain the carbonates of soda, and magnesia and silica; none

<sup>1</sup> *Prof. Wurzer on the Sulphureous Springs of Nenndorff in Hesse*, 1824, p. 92.

of which could be found by Salzer in 1811. Similar changes have been observed by Bischof, in regard to the waters of Roisdorf, near Bonn. In August 1824, 10,000 parts contained 4.48 of the sulphate, and 17.89 of the muriate of soda. In April 1825, the quantity had augmented to 5.35, and 19.32. The waters of Cheltenham, in England, are well known for the inconstancy of their saline impregnation, it being necessary every few years to sink fresh wells to obtain water of the requisite strength. In the old well at Harrowgate, Dr Garnett in 1794 found 754 grains in a gallon, while Dr Scudamore in 1819 found it increased to 848; but whether this change is owing to the seasons, or whether it depends on a permanent and progressive augmentation of the strength of the water, can only be determined by a continued series of observations made at determinate intervals.

The gaseous are subject to still more striking changes in some springs than the solid constituents. The causes of these changes are very obscure; and in the present state of our knowledge, altogether inexplicable. They are materially affected, no doubt, by the seasons, the atmospheric pressure, and the electric tension of the aerial medium, but are probably still more to be ascribed to the operation of unknown processes in the interior of the earth. Wurzer informs us that the cold sulphureous spring at Stockhausen in Thuringia, all on a sudden disengaged a large quantity of sulphuretted hydrogen, which continued for four months with unabated vigour (from November 1817 to February 1818), when it as rapidly diminished, and the sulphureous taste of the water nearly ceased altogether. Bergman observed considerable differences in the waters of Medwi in Sweden, with regard to their quantity of gas.

These changes are generally, however, most distinctly seen in springs which contain a large quantity of free carbonic acid; on these also the atmosphere seems to exert the most marked influence. Pickel found the Raggozi well at Kissingen in Franconia, to yield, in the month of June, not long before a storm, 170 cubic inches



in a minute, the temperature of the air being  $82^{\circ}$ ; in the month of July, in wet weather, only 110 cubic inches, temperature of air  $64^{\circ}$ ; and the very day after, it was augmented to 140 cubic inches<sup>1</sup>.

The springs of Riepoldsau, already noticed, were found by Klaproth, in 1806, to contain not much more than half the quantity of carbonic acid, afterwards found in 1811 by Salzer; it ought, however, to be observed, that the former analysis was executed at a distance from the source, the other on the spot. The gaseous exhalations or springs, if we may so term them, also experience remarkable changes which depend on causes with which we are quite unacquainted. This has been observed on different occasions at Pyrmont, the Laacher Lake in the Eifel range on the Rhine, in the Vivarais and the Grotta del Cane near Naples. The sudden changes in temperature and impregnation which often takes place in thermal waters, in consequence of earthquakes, will be treated of when I come to consider their volcanic relations.

Before concluding this subject, I would call the attention of the reader to the remarkable oscillation which, in some cases, seems to take place between the different constituents of mineral waters, so that, while their total quantity remains the same, their relative proportion varies considerably. This is evidently the case with the thermal springs of Ems in Nassau, according to the analysis of Struve<sup>2</sup> the following is a view of their composition:—

	At one time.	At another.
Carbonate of Soda, . . .	13.26	10.75
Sulphate of Ditto, . . .	0.23	0.42
Muriate of Ditto, . . .	5.06	7.67
	<hr/> 18.55	<hr/> 18.84 <sup>3</sup>

From which it is seen that, in both cases, the total quantity is nearly the same; the amount of pure soda is also

<sup>1</sup> Trommsdorff, *Journal der Pharmacie*, xi. 344.—<sup>2</sup> *Über Nachbildung d. Natürlich. Heilq.* pt. i. 1824, p. 15.

<sup>3</sup> Kastner (*Archiv.*) states the same quantity of water (16 oz.) to contain 24 gr. of solid matter, 20 of carbonate of soda, 1 of the sulphate, and 3 of the muriate.

the same, it is only the proportion of acids to the base which varies. Hermann, who has analyzed, at different intervals, the brine-spring at Halle, states, that the muriate of magnesia is constantly on the increase, which is accompanied with a proportional diminution of the muriate of lime : in 1798, the proportions were one part of the former to seven of the latter ; in 1823, they were as two to one. Perhaps the deviations which occur between every succeeding analysis of the waters of Marienbad in Bohemia, may be referred to this head. That these are owing to real changes in the qualities of the water we are assured of, both by the high character of the chemists by whom the analyses have been executed, and the very great difference between the results<sup>1</sup>.

These examples of the changeability or unchangeability of the impregnation of mineral and thermal waters might have been greatly increased in number, but I have confined myself to those analyses which rest upon the authority of the most experienced chemists, and which enter into that exactness of detail which is alone available for the purposes of rigorous comparison.

I have entered thus far into the consideration of the constancy of the impregnation of mineral waters, from a conviction which will, I am sure, be shared by the reader, on an attentive consideration of the foregoing facts, that if we could succeed in establishing that no change has taken place during a long succession of years, may be of ages, it would be one of the most interesting phenomena connected with their history. It must certainly be held to be one of the most remarkable processes carried on in the interior of the globe, the furnishing a mineral water with such enormous quantities of saline matter without any perceptible diminution, even for the short space,—short, when compared with the probable date of their origin,—of thirty or forty years.

An attention to the periodical effects of the seasons in modifying their composition, is also of much import-

<sup>1</sup> *Gilbert*, in Appendix to Berzelius *Untersuchung*, u. s. p. 122.

ance to the chemist in fixing the time of his analysis, when he wishes to compare it with those of his predecessors. These periodic changes may cause two analyses, half a century distant from each other, to indicate slight differences in composition which are not owing to any permanent change, but merely to the different seasons in which they have been constituted. Perhaps the very cause of the close accordance of Klaproth's and Berzelius' analyses of the Karlsbad Sprudel was their having been both executed at the same season, the former in July 1789, and the other in the bathing-season of 1822. The same cause may also perhaps be the reason of the identity of Westrumb's and Bischof's analyses of the Selters water, the first being performed in June 1787, and the other towards the end of April 1825. And it is not improbable that the difference between Bischof's analysis of the Koisdorf water in August and April, is entirely owing to the contrast of the seasons. The researches of Westrumb into the Pyrmont waters discover another caution of not less importance to the accurate and enlightened chemist, whether the water upon which he is experimenting has been drawn after the spring has been at rest for some time, or when it has been continually agitated and nearly exhausted by a continual demand for the water. In the latter case, the quick running off of the water will prevent its having time for dissolving its ordinary quantity of saline matter, and, if analyzed at such a time, it will indicate a smaller quantity than properly belongs to it. Thus the year 1788, in which Westrumb found these springs to contain a smaller proportion of the sulphate of lime than in 1783, was remarkable for the immense quantity of the water drawn for exportation. All these precautions ought to be attended to, which naturally flow from the preceding observations, and it is probably to a neglect of them that those discordances occur which have been the occasion of many rejecting the value of chemical analysis altogether in the science of mineral waters. For we ought never to forget that great changes may take place in the processes which preside over the for-



mation of a mineral water, without any *great* change being perceptible in its composition. Even in the richest waters, the quantity of solid matter is nothing when compared with that of its aqueous menstruum; what a prodigious degree either of rain or of drought must precede either the diminution or the augmentation of a salt by even a single grain.

### SECTION III.

#### COMBINATIONS OF THE CONSTITUENTS OF MINERAL SPRINGS.

HITHERTO mineral waters have been viewed in their decomposed state, as the results of the analysis of the chemist; it is now time to consider them in their undecomposed state, as the results of the synthesis of nature. This will be found a much more difficult task. Nature seems to have hid from the scrutiny of the philosopher the operations of her secret laboratories; so that, notwithstanding the labours of so many analysts and philosophers of celebrity, we are as yet only in possession of a few hypotheses of greater or less plausibility. Although chemistry has in modern times determined, with the greatest exactness, the essential constituents of mineral springs, and the quantities of these constituents, and has even enlarged our knowledge of their constitution by the discovery of many new ingredients; although it is in fact, as Alibert remarks, for mineral waters what anatomy is for the human body, or, in other words, it constitutes the very basis of all our knowledge of their composition; yet it ought not to be forgotten, that it dissolves the bond of connexion between the different substances as they are associated by the hand of Nature. Even after the most laborious researches, the analyses are not always satisfactory, the different combinations are often founded upon hypothetical, and even altogether arbitrary, grounds; and the results obtained by the

most eminent chemists from the same springs are by no means always in accordance with each other, and are even in some cases directly at variance with the well-known laws of chemical affinity; and, lastly, the medicinal effects of a water are often altogether different from the known properties of what appears to be its predominant constituent.

For these reasons, it has been not unfrequently asserted that chemical analysis always gives products instead of educts. This, as we will afterwards see, is so far true, that the salts obtained from a mineral water by evaporation, or any other process, may be produced during the operation. The acids and bases, however, which go to constitute these salts, without doubt pre-exist in the solution from which they are afterwards separated, unless we are disposed to grant to the chemist the power of forming them during his analysis,—an alchemical idea which does not fall far short of the ancient reveries regarding the philosopher's stone.

One of the first circumstances which excited a suspicion of the correctness of the ordinary methods of analysis, or of our being acquainted with the true constitution of mineral waters, was the indication in the analyses of many waters of the coexistence in a state of solution of salts quite incompatible by the laws of affinity, such as of carbonates, muriates, and sulphates. Such a contradiction could only depend on an error in the method of research, or on a composition and combinations of a peculiar kind. Another circumstance equally unaccountable, was the obtaining a quantity of some highly insoluble salt, such as the sulphate, and still more the carbonate, of lime, far greater than was capable of being held in solution, except with the aid of a large excess of carbonic acid, which was not always present.

Chemists had been accustomed to employ two modes of discovering the composition of a water,—that by *evaporation*, or what is usually called the direct method by which they obtained a certain number of neutral salts ready formed,—and that by the application of certain *reagents* which yielded an assemblage of acids and bases,

from which elements they subsequently inferred the composition of the water. The latter method has always been considered as entirely subordinate to the former, which was alone thought to indicate the real ingredients, and enable us to estimate their quantities with precision.

The above inconsistencies showed that some lurking defect attached to this method. An opinion has been adopted by some<sup>1</sup>, that, in their natural state, the ingredients of mineral waters are amalgamated into one whole, a single salt, consisting of the simultaneous combination of all the acids or bases, and chiefly characterised by "unity and intimacy of composition." Independently, however, of such a compound being hardly conceivable by the mind; its admission would be at variance with all known physical laws, and would annihilate all permanency and distinction of characters between bodies. We must therefore suppose that the acids and bases are united so as to form a certain series of binary compounds. The next question which then arises is, What are the laws which regulate their formation?

In the present state of chemical science, we have no direct means, no *experimentum crucis*, by which we can verify our conclusions. Several concurring circumstances, however, would lead us to infer that it is in determining the real constitution of mineral waters, we will find the most beautiful application of the doctrines of Berthollet regarding the influence of mass in modifying the force of affinities. These teach us to believe, that, when several salts are dissolved in the same solution, even those which do not decompose each other, a certain reaction ensues, each acid combines with a portion of each base, and there arise a series of compounds resulting from the reciprocal union of all the elements; the number of which is equal to the product of the sum of all the acids into the sum of all the bases. If we mix, for example, solutions of caustic soda, and sulphate of potash, there is formed a certain quantity of sulphate of

<sup>1</sup> Osann Darstellung, p. 12.



soda, and in such proportion that the remaining uncombined portions of each base are exactly equal to each other. But if the soda should have been previously in the state of muriate, a more complicated reaction ensues, a portion of the muriatic acid combining with a portion of the potash. From the original mixture of the two salts, there result four, so long as they remain in a state of solution, but we obtain only two by evaporation, for the reasons which Berthollet has so beautifully demonstrated.

These views have been unreservedly admitted by some, and as absolutely rejected by others. Viewed theoretically, when we reflect on the extraordinary power of solution in promoting the combination of bodies which, in their solid state, remain quite inactive with respect to each other, we must suppose an extraordinary mobility to be possessed by the minute particles or atoms of matter as they exist in the fluid state. Why, therefore, should not these atoms obey the impulses of the weakest affinities, when no obstacles oppose themselves to their free action? It may be said, that the strongest affinities alone are in operation, when heterogeneous substances are brought into contact. This may certainly be the case when an insuperable obstacle is opposed to the free reaction of the minutest particles of bodies, such as is presented by the state of solidity; but when their free transmission is permitted by a state of solution, there is no reason why the weaker as well as the stronger affinities should not be in operation. For, as Berthollet observes, “the chemical action of a solvent may be neglected with respect to the state of combinations, when other affinities much more powerful produce them; but it acquires importance in proportion as these affinities are weaker, and, finally, by its relative force, it decides in some circumstances the compounds which are formed<sup>1</sup>.”

Many direct experiments have been made by different eminent chemists, both in support and for the refu-

<sup>1</sup> Chemical Statics, § 217.

tation of the doctrines of the French philosopher, or, in other words, to determine the state of different salts when in cotemporaneous solution in the same menstruum. I shall only cite the following<sup>1</sup>, which appear to me only explicable on the principles above stated.

A. If sulphuric acid is added to a solution of the sulphate of lead in dilute nitric acid, there immediately follows a precipitation of a part of the salt. Now, it cannot be conceived that an acid can act as a precipitant to one of its own salts, which would be the case if the sulphate of lead existed unchanged in the nitric acid. The oxide of lead being already saturated with sulphuric acid, any new portion of acid could not combine with the base, in order to develop a precipitate of the salt. We can at most suppose, that the free acid has deprived the nitric acid of the power of holding the whole of the sulphate of lead in solution (which would suppose a degree of affinity to exist between these two acids which has not yet been demonstrated), or that the salt is less soluble in the mixture of the two acids than in the nitric acid singly. But the explanation of the phenomenon is exceedingly simple, if we suppose that the oxide of lead has not all existed in the solution in the state of sulphate, but has been distributed in certain proportions between the sulphuric and nitric acids, according to its respective affinity for each. An addition of the stronger acid would, of course, in this case, separate the portion in union with the nitric acid.

B. The sulphate of potash precipitates almost the whole of the sulphate of lead from its solution in the acetate of ammonia. There would be nothing extraordinary in this, if sulphate of potash and acetate of ammonia mutually decomposed each other, giving origin to acetate of potash and sulphate of ammonia; because, in that case, the sulphate of lead would be deprived of its solvent medium, the acetate of ammonia. But as this is not the case, the precipitation of the metallic salt

<sup>1</sup> *Bischof, Über Vulk. Mineralquelle, p. 343.*

must depend upon other causes. According to the principles of Berthollet, when aqueous solutions of sulphate of lead and acetate of ammonia are brought together, besides these two salts, there are formed sulphate of ammonia and acetate of lead. When, therefore, sulphate of potash is added, it takes a quantity of acetic acid proportioned to its degree of affinity; and the liberated sulphuric acid being added to that already present from the augmentation of its mass, causes a partial precipitation of sulphate of lead.

If we should ask the quantities of the four salts contained in the solution of the first experiment, it must be admitted that this is incapable of being determined, although we should be perfectly acquainted with the relative proportions of sulphuric and nitric acids, and of the oxide of lead, as it depends not only on the quantities of each of these substances, but also on the reciprocal force of the affinities of each of the acids for the base; for the determination of which, chemistry as yet furnishes us with no data.

C. Murray has instituted some experiments to ascertain whether sulphate of soda could exist in a solution along with muriate of lime, without decomposition or precipitation of sulphate of lime<sup>1</sup>. There were added for this purpose to different portions of the Dunblane water, four ounces each, five, ten, fifteen, twenty, and at last thirty grains of sulphate of soda, without producing any deposit; even after twenty-four hours the solution had not the slightest turbidity. In most of these cases, the quantity of the sulphate of soda was sufficient to convert all the muriate of lime in the water into sulphate; and, according to the known solubility of this sulphate, the quantity of water was not sufficient to hold it in solution. This quantity was even reduced so far by evaporation, without any precipitation following, which seems to prove that no sulphate of lime (or very little) had been formed; and consequently, that sulphate

<sup>1</sup> On the Analysis of the Mineral Waters of Dunblane, in Edin. Phil. Trans. vii. 1815, p. 470.



of soda, and muriate of lime, may coexist in a very dilute solution without mutual decomposition.

If such be the state of the binary compounds in the state of solution presented to us by nature, a new arrangement ensues during the process of evaporation and concentration. If the chemical action of substances is exerted not only in the ratio of their affinity, but also of their quantity, then this action must diminish in proportion as saturation advances. As this period will arrive first with regard to the most insoluble compounds, the affinities of their elements will be the first to overcome the counteracting effects of solution. This explains why the carbonate and sulphate of lime are often precipitated in much larger quantity than what could possibly have been previously held in solution, in the known state of dilution, and with the known quantity of carbonic acid. I am aware that it has been stated<sup>1</sup> that, even in those springs which are most strongly impregnated with fixed matters, the water is in such excess that it is capable of dissolving completely even the most insoluble substances. With respect to the carbonate of lime, Kirwan has drawn the conclusion from many experiments of Cavendish, Bergman, and Berthollet<sup>2</sup>, that, when its proportion to the water is as 1 to 120,000, it requires half its weight of carbonic acid to hold it in solution; and if the proportion of water is still more considerable, a smaller weight of the acid will be sufficient, till at last the quantity of water may be so increased that no excess of acid whatever will be required to hold the carbonate in solution. And, conversely, the smaller the proportion of water with respect to the carbonate of lime, the greater must be the excess of acid necessary to hold it in solution. And if the weight of free acid, united to the water, exceeds that of the carbonate, it will dissolve it, whatever be its proportion to the water. If we merely take the Buxton waters in this country as an example, the proportion of carbonate to the water is as 1 to 5600,

<sup>1</sup> *Bischof*, Vulk. Mineralq. p. 351.—<sup>2</sup> *Kirwan* on the Analysis of Mineral Waters, 1799, p. 20.

while the excess of acid is only one-fifteenth of its weight. It must be allowed that a difficulty occurs in this instance, of accounting for the solubility of the earth upon any principle, as the quantity of base is much more than enough to saturate the whole of the other combined acids to the exclusion of every other. In a case not nearly so exaggerated as the present, where the relations of the earth to its solvent were as 1 to 9389, and the weight of carbonic acid a little less than one-half, Bergman was so much surprised that he thought the earth could be only mechanically suspended<sup>1</sup>.

Berzelius supposes that all the insoluble carbonates exist in the state of bicarbonates. Not unfrequently, however, in those waters which contain much of the carbonate of soda, this greatly contributes to their solubility, as well as that of the highly insoluble fluates and phosphates of lime, without the aid of free acid; indeed, some of these last are not more soluble in water highly impregnated with carbonic acid than when pure. Thus, Berzelius mixed fresh prepared and still moist fluat of lime with water, which he then impregnated with carbonic acid; the clear solution was filtered and then boiled; on the expulsion of the gas, there scarcely appeared a perceptible trace of fluat of lime. The same earth was mixed with another portion of water along with carbonate of soda, and again saturated with carbonic acid; this solution became very turbid by boiling, and deposited the fluat of lime. From which it appears that the bicarbonate of soda is the true solvent of the fluat of lime in aqueous solutions, which, whether it

<sup>1</sup> *Bergman* on the Analysis of Mineral Waters, i. 190. For the sake of comparison, I shall subjoin a tabular view of the solubilities of the nine principal salts which occur in mineral waters: 100 parts of water at 60° F. dissolve of—

Carbonate of Lime,	.	.	.	0.	parts.
Magnesia,	.	.	.	0.04	
Sulphate of Lime,	.	.	.	0.2	
Muriate of Soda,	.	.	.	35	
Sulphate of Soda,	.	.	.	37	
Carbonate of Soda,	.	.	.	50	
Sulphate and Muriate of Magnesia,	.	.	.	100	
Muriate of Lime,	.	.	.	400	

can be extended to other very insoluble earthy salts, further experiments alone can determine. Phosphate of lime is much more soluble than the fluuate in carbonated water, and its solubility is not increased by the presence of soda.

In those waters where one base greatly predominates over every other, the results of analysis cannot differ much from the truth. This is the case with the lime in the instance of Buxton, just noticed. In the Karlsbad water, the amount of the soda is so considerable that the quantities of the other ingredients can be but small. It probably, however, contains minute proportions of the sulphates and muriates of lime and magnesia, and a larger amount of carbonate of soda than what is indicated by analysis; all of which, however, undergo decomposition during evaporation, which gives sulphate, carbonate and muriate of soda, carbonates of lime and magnesia. Even those substances which the recent researches of the Swedish chemist have discovered in minute proportion, the fluuate and phosphate of lime, the carbonate of strontian, and phosphate of alumina, must be subject to the same equal distribution, although, with respect to them, the operation of these laws will be much less apparent. It is thus not only possible, but is the most probable supposition, that what are called incompatible salts co-exist in a mineral water. Another question, however, is, whether incompatible salts are ever found in the residuum obtained by evaporation,—whether, for example, the carbonate of soda is ever seen conjoined with earthy sulphates or muriates. This may be decidedly answered in the negative: for, by a sufficient degree of concentration, we can always produce the decomposition of an earthy sulphate or muriate by the carbonate of an alkali. If, therefore, in the older analyses, which were always by evaporation to dryness at once, we ever find mention made of the coexistence of incompatible salts, we may ascribe it to some error in the operation, as in those which have been made by the first chemists, by Westrumb, Bergman, Klaproth, &c. we never see mention made of incompatible salts.



Can a subordinate argument be drawn in favour of viewing the composition of mineral waters upon the principles of Berthollet from their medicinal powers? Upon no view can we so well explain the great variety of effects which they produce upon the human body, since the predominance of a single acid or a single base will give rise to the formation of a great variety of different compounds in a water which would yield by analysis exactly the same constituents as another. Thus, suppose that two mineral waters indicated exactly the same constituents, carbonate of soda, muriate of soda, and carbonate of lime, and differed only in the quantity of the last ingredient, then, according to this view, the different effects of these two waters would not depend merely on their different proportions of carbonate of lime; but also, in proportion to the relative masses and affinities of the carbonic acid and the lime, would produce entirely different quantities of the carbonate and muriate of soda, as well as of carbonate and muriate of lime.

A modification of the theory of Berthollet has been proposed by Murray<sup>1</sup>, suggested by the analysis of the mineral waters of Dunblane. Setting out from the same principles, "that the state of combination may be modified by the analytic operations, and that the binary compounds obtained may not be precisely those which existed in the water," he supposes that the acids and bases are not in simultaneous reciprocal combination. Berthollet maintains that the number of salts is equal to the product of all the acids into the bases; while Murray is of opinion that the most soluble compounds are the ingredients of the water, and that the less soluble, which are obtained by evaporation, depend on the influence of the force of cohesion. If the force of cohesion can so far modify that of chemical attraction, as to establish among salts in a state of solution those combinations which form the least soluble compounds, the reverse of this force, the power of solvent, ought to pro-

<sup>1</sup> Edin. Phil. Trans. vii. 468. 1815.

duce the opposite effect, and cause the formation of the most soluble compounds. He adduces, as an example, the case of the Dunblane water. The salts obtained are the muriate of soda, muriate of lime, and sulphate of lime. It is very possible, however, that the last is not an original constituent, but formed during the process of decomposition. The sulphuric acid may rather be in union with the soda; but in the concentrated solution reacts on the muriate of lime, and by mutual decomposition forms portions of muriate of soda and sulphate of lime. A proof that the sulphate of lime is formed during the evaporation, by the reaction of sulphate of soda and muriate of lime, is, that, by the addition of the former, the quantity of sulphate of lime obtained is considerably increased. When ten grains of crystallized sulphate of soda are added to a wine pint of the Dunblane water, we obtain by evaporation seven grains of sulphate of lime, which is twice as much as the same quantity of water would have yielded without this addition. These experiments, as Murray very judiciously adds, do not absolutely establish the conclusion that, in this water, the sulphuric acid is united to the soda; they render it, however, extremely probable, especially when we take into account the effects of the water. A curious fact, in confirmation of this idea, is, that in all the analyses of mineral waters since the time of Bergman, when they can be supposed to have been executed with any precision, where sulphate of lime exists, the muriate of soda is also present. Where the carbonate of lime is a product of the analysis, upon the same principles it will, in most cases, exist in the water as the carbonate of soda.

If these views are admitted, it is obvious that the impregnation of a large proportion of mineral waters must be expressed altogether differently. Sulphate of lime and muriate of soda, ingredients which enter into the composition of such a variety of springs, must be changed into muriate of lime and sulphate of soda. There is no direct method of proving by experiment this formation of the sulphate of lime, as it is constantly produced in whatever way we perform the analysis of the water. In

the same way if, as is the case with the great class of alkaline waters, besides a large proportion of carbonate of soda, there exist also carbonates of lime and magnesia, with muriate of soda, the true constitution will be carbonate of soda, but in larger quantity than obtained by analysis, muriate of lime, and muriate of magnesia. During the process of evaporation, however, the carbonated alkali decomposes the earthy muriates, and gives rise to the formation of a larger quantity of muriate of soda than naturally existed in the water, and to the carbonated earths, which did not exist there at all.

Murray considers his views as of peculiar interest in accounting for the virtues of waters, which were inexplicable by the old methods of analysis. Let us take the Dunblane water in illustration. The sulphate of lime is an inert substance ; it can therefore contribute nothing to the medicinal effects of the water ; even the presence of the muriate of soda cannot have much influence. But, if the elements of these salts are supposed to form other compounds,—if the sulphuric acid is combined with soda, and a portion of the muriatic acid with lime,—the quantity of the muriate of lime will easily account for the efficacy of the water in generally morbid states of the body, particularly of the scrophulous character ; and its cathartic powers will be owing to the sulphate of soda, for without this compound they are quite unintelligible, as the water contains no other salt to which we can ascribe these qualities. The same principles he considers as capable of giving a satisfactory explanation of the virtues of the waters of Bath, Cheltenham, and Harrogate, in this country, the active ingredients of which are very analogous to those of Dunblane, on which his views were originally founded. This theory, however, which is developed by its author with equal elegance and modesty, is open to many serious objections, both in a chemical and medicinal point of view. The experiments on which it is founded can all be explained upon the principles of Berthollet. As Berzelius observes, he overrates the difference between the results of analysis and the actual composition. For, although theory



would lead us to infer that the acids and bases do not form those compounds which we obtain in our experiments, are we for that reason entitled to group these elements upon uncertain if not arbitrary hypotheses? It is not very apparent why these salts only should exist in a mineral water, which form the most soluble compounds. With regard to the sulphate of lime and muriate of soda, and even the carbonated earths, when a small quantity of carbonic acid is present, the quantity of water is in almost every case amply sufficient for their perfect solution. Muriatic acid, lime, and magnesia, being the most common of the elements of mineral waters, and the muriates of lime and magnesia the most soluble of their compounds, these salts would exist in almost every water. This is not absolutely impossible, but will hardly furnish a satisfactory explanation of the diversified effects of these agents upon the animal economy: whereas, according to the Bertholetian philosophy, a water will equally contain the muriates of lime and magnesia when muriatic acid, lime, and magnesia, are separately present. These salts will, however, according to the masses of the contemporaneously existing acids and bases, form the utmost variety in regard to quantity, from that scarcely perceptible, till they become the predominant constituents.

Whatever opinion may be entertained of Murray's theory of the composition of mineral waters in their undecomposed state, no one will be disposed to deny the great practical benefits he has conferred upon the scientific traveller and the physician, by his "General Formula for the Analyses of Mineral Waters<sup>1</sup>." If it be true, as the preceding illustrations go far to prove, that evaporation yields salts which are more frequently products of the operation than original ingredients, the true composition must be determined on grounds different from what is actually obtained. No more information is gained from obtaining ready formed a certain series of binary salts, than by discovering the quantity of their elements, from

<sup>1</sup> Edin. Phil. Trans. viii. 259; 1817.

which we can afterwards infer their binary compounds from the law of definite proportions. The latter mode, however, of obtaining, in an insulated form, the acids and bases, is infinitely easier in the execution than that of obtaining separately the compound salts. It is a very difficult and laborious process, and for that reason liable to great inaccuracy, to separate entirely the different salts by the process of crystallization, even with the assistance of alcohol and water at different temperatures. Nothing, however, is easier than, by the application of the doctrine of definite proportions, to estimate the total quantity of sulphuric acid from precipitation by barytes, of lime by oxalic acid, or of muriatic acid by the oxide of silver. This method, therefore, although not dispensing with a detailed chemical examination, is invaluable to the physician, as enabling him, by a few preliminary essays, to form an opinion on the property of a water proposed as a medicinal agent in the cure of any individual disease. Combining together all the methods of analyses, we can always express the composition of a water in the four following methods :

1. The quantity of acids and bases.
2. The number of binary compounds resulting from the reciprocal combination of all the acids with all the bases<sup>1</sup>.
3. The quantities of binary compounds inferred from the principle that the most soluble salts are the ingredients.
4. The quantities of the binary compounds, as obtained by evaporation or any other direct method.

Let us take the Bath waters as an illustration :

1. Sulphuric acid ; muriatic acid ; soda ; lime.
2. Sulphate of soda ; muriate of soda ; sulphate of lime ; muriate of lime.

<sup>1</sup> The quantities of these compounds cannot be expressed, as they depend on two conditions, only one of which can be known by the chemist : *a*, On the quantities of the elements ; *b*, On the reciprocal affinities of these elements.

3. Muriate of lime; sulphate of soda; sulphate of lime<sup>1</sup>.
4. Sulphate of lime; muriate of soda; sulphate of soda.

When the results are expressed according to 4, the analyses of different chemists are more comparable with each other; and the physician can arrive at more certain conclusions regarding its medicinal powers, from its greater or less similarity to those with the effects of which he is already familiar by actual experience.

Several chemists have endeavoured to apply to the results of the analysis of mineral waters the doctrine of definite proportions; regarding every spring as a single chemical compound, the different elements of which bear a determinate relation to each other. This view was first brought forward by Professor Döbereiner<sup>2</sup>, and applied by him to the springs of Selters, Karlsbad, Aachen, &c. It has since been illustrated by Wurzer and Reuss, the latter of whom has extended it to the waters of Marienbad.

When we consider that a mineral spring is a simple solution of certain salts and gases, it is not easy to conceive how their composition can be subject to so precise a rule; for water is capable of dissolving the most various salts in all proportions up to the point of saturation. But as many of the ingredients found in mineral waters form definite chemical compounds, which are taken up by the water in the process of mineralization, it is not unlikely that some of these may actually retain the same relations to each other as before the contact of this new agent. This, however, must be extremely rare, when the long course is considered which a water in most cases travels previous to its emergence from the bowels of the earth; the great variety of strata with which it must come in contact, most of which contain different soluble matters capable of being taken up by

<sup>1</sup> The proportion of sulphate of lime is so great, that part of it, even upon this view, must pre-exist in the water.

<sup>2</sup> Über die Chemische Constitution der Mineralwasser, 1821, pp. 11, 15, 23.



the water, and some of which may even decompose the substances already in solution. To use a comparison of Berzelius, we might as well suppose that the component minerals of a compound mountain rock, of granite for example, are aggregated according to definite chemical proportions, because this is the case with the elements which constitute the individual minerals. We are not entitled to apply this principle to the prevailing ingredients only, and leave out of view the substances which enter in smaller quantity into their constitution<sup>1</sup>, which the author of this theory has been forced to do, from the prodigious excess in the number of the atoms of the former over those of the latter. All the ends of the chemical analysis of mineral waters would be defeated, if the minute ingredients were banished from their composition upon these hypothetical principles.

As the discrepancies between the analyses of the same water by different chemists have been not only a frequent subject of remark, but have not a little contributed towards producing a general distrust regarding the value of the chemical examination of this class of bodies altogether, it may be useful to inquire for a little into some of the causes of these differences. This inquiry is besides in some degree necessary, when we are desirous of comparing together the results of the analysis of two mineral waters, one of which has been performed by the old, the other by the new methods, and of thence inferring their similarity or dissimilarity from each other.

First, then, it is requisite, in the analysis of every water, either to employ exclusively the method of re-

<sup>1</sup> Döbereiner has entirely omitted, in his analysis of the Selters water, the iron, manganese, alumina, phosphoric acid, and silica. Can this be from their not coinciding with his views? In the Karlsbad waters we find a tolerable approximation to chemical proportions, if we take into account merely the prevailing ingredients. According to the analysis of Berzelius, they will be :

Sulphate of soda, . . . .	27.87 = 18 atoms.
Carbonate, . . . .	12.86 = 12
Muriate, . . . .	10.61 = 9
Carbonate of lime, . . .	3.05 = 3
of magnesia, . . . .	1.72 = 2

agents<sup>1</sup>, or, if the older method be preferred, to evaporate to perfect dryness<sup>2</sup>. Every intermediate method leads to uncertain results. When a water, which contains, among other salts, the carbonate of soda, is evaporated to dryness, and the residuum dissolved in water, it is well known that the solution always contains a portion of magnesia and lime. These earths are only fully separated when the solution is again evaporated to dryness, and the residuum, after being heated to redness, is again acted on by water. But if this second process is not instituted, and the quantity of carbonate of soda is ascertained by neutralizing the first solution with sulphuric acid (as was formerly the common practice) there is of course obtained a certain proportion of the sulphates of magnesia and lime; or, if muriatic acid be employed, the muriates of the same bases. A still greater quantity of magnesia must remain associated with the more soluble salts, when the original evaporation of the water is not carried to perfect dryness, but only till the precipitation of the insoluble matters is apparently complete, and the supernatural liquor is separated by filtration. In this case another source of error arises; for, if the water should contain, along with carbonate of soda, the sulphate or muriate of lime or magnesia, when the evaporation is only carried to a certain

<sup>1</sup> Besides Murray's method, compare *De Dombasle*, *Essai sur l'Analyse des Eaux Naturelles par les Reactifs*, 1810.

<sup>2</sup> It is a principle now generally admitted by analysts, that the salts found in mineral waters ought to be estimated in their dry state, entirely deprived of their water of crystallization. Kirwan was the first who placed this in a clear point of view. Many, however, of the most eminent of the older hydro-analysts were of a different opinion. Thus both Bergman and Fourcroy expressly state that the quantity of neutral salts is to be estimated by their weight in the crystallized state, because in that state they exist in waters. But the virtues and powers, both chemical and medical, reside solely in the saline particles; the water of crystallization is devoid of all power. Besides, when a salt is dissolved, no part of its menstruum can be distinguished as water of crystallization, there being no crystallization at all. As Kirwan observes, "The only difference between water of crystallization and other water is the difference of states, the one being solid and the other liquid; but when the salts are dissolved, all is liquid; this difference then exists no longer."

degree of concentration, not to perfect dryness, the salts of lime and magnesia are only partially decomposed. Brande's experiments<sup>1</sup> have shewn that carbonate of soda and sulphate of magnesia do not decompose each other, when each is dissolved in about 60 parts of water; nor the same alkaline salt and the muriate of lime, when each is dissolved in about 6000 or 7000 waters. These earthy salts, when the water is evaporated to perfect dryness, will be entirely converted into the carbonates of lime and magnesia; but, if we stop half-way, there will be a mixture of the soluble and insoluble earthy salt.

Vauquelin and Thenard have directed our attention to another source of error, suggested by their analysis of the chalybeate water of Provins, near Paris. They found a small proportion of the carbonate of soda. But it is very unlikely that it existed naturally in the water, because it would have been decomposed by the muriate of lime present. Besides, as they observe, even admitting that it previously existed in the water, it could not have been dissolved by the alcohol employed in the treatment of the deposit. It was probably owing to the decomposition of a small portion of the muriate of soda by the oxalate of ammonia, by means of heat; a small quantity of the muriate of ammonia being formed, which was all volatilized by the total decomposition of the oxalate of soda. The French chemists established the correctness of this conclusion by direct experiment; as when they exposed together to a red heat muriate of soda and oxalate of ammonia, carbonate of soda was a constant product. As the Provins water, however, when concentrated, restored the colour of litmus, which had been reddened by an acid, four litres of the water were evaporated to about 100 grammes; this was filtered to separate the insoluble carbonates, and then evaporated to perfect dryness. Although it then also indicated an alkaline reaction on litmus, it shewed no sign of effervescence with acids, and did not precipitate lime-water.

A *third* cause of error may depend upon the different

<sup>1</sup> Schweigger's Journ. f. d. Chem. N. S. xiii, 152.



effects of various solvents in promoting or retarding the reaction of different compound salts, and shews the necessity of farther experiments in order to determine the laws of double affinity in different menstrua. Alcohol, for example, may determine the mutual reaction of two salts, which in an aqueous solution remain quite inactive with respect to each other. Thus if dry crystallized sulphate of magnesia and dry muriate of soda are well triturated together<sup>1</sup>, and the mixture is then digested for some time, or boiled for a few minutes in strong alcohol, the alcohol, after being poured off, gives after some minutes a distinct precipitate of magnesia, on being treated with caustic ammonia. But if each of these salts is boiled separately in alcohol, no precipitate is produced; which shews that the alcohol, in this case, produces a mutual decomposition of these two salts by its solvent power and affinity for the muriate of magnesia<sup>2</sup>.

It was a common practice among the older analysts of mineral waters, to assume the alcoholic extract of the residuum to be the muriate of lime; and they very seldom had recourse to evaporation for the purpose of verifying their conclusions, on the supposition that this salt only, of those commonly found in these waters, was soluble in absolute alcohol. The following experiment, however, of Bischof<sup>3</sup>, will shew the fallacy of this conclusion. A piece of marble was dissolved in muriatic acid, and evaporated to dryness. A few drops of the aqueous solution of the muriate of lime were added to one of carbonate of soda, with the precaution to leave a certain quantity of undecomposed carbonate in the solu-

<sup>1</sup> *Grotthuss*, in *Schweigger's Journal*, xviii. 113.

<sup>2</sup> The same chemist observes: "That, by repeated solutions and evaporations of a mixture of sulphate of magnesia and muriate of soda in alcohol, we at last obtain a residuum consisting entirely of sulphate of soda, the alcohol yielding only muriate of magnesia. When these two salts are dissolved together in water, the sulphate of magnesia separates before the muriate of soda. When sulphate of lime and muriate of soda are boiled together in alcohol, there is formed some muriate of lime and sulphate of soda. It is therefore more than probable that the muriate of magnesia and sulphate of soda are often formed during the analysis, by treating the saline residuum with alcohol."

<sup>3</sup> *Vulk. Mineralq.* p. 385.

tion. The precipitate was therefore carbonate of lime, and the liquid contained the muriate and carbonate of soda;—three salts which are not unfrequently obtained by the evaporation of a mineral water. The whole was evaporated to dryness, the residuum gently boiled in alcohol of 97.5 per cent. The alcohol might have produced a partial decomposition of the carbonate of lime and muriate of soda into muriate of lime and carbonate of soda, on account of its great solvent power over the earthy muriate. Accordingly the filtered solution was precipitated by oxalate of potash. Professor Bischof was soon, however, convinced that this was owing to the alcohol itself, not to the presence of lime, in consequence of the insolubility of the oxalate of potash in this menstruum; because, when the liquid was evaporated to dryness, and the residuum dissolved in water, not the slightest turbidity was produced by this reagent. No decomposition was therefore occasioned by the alcohol, which had merely dissolved the muriate of soda. The circumstances were here very analogous to what occurs in a mineral water consisting of the same constituents. No muriate of lime was, however, found along with the carbonate of soda; although it is not improbable that, by the long continued action of alcohol on carbonate of lime and muriate of soda, a partial decomposition might ensue<sup>1</sup>; particularly as it has been established that carbonates of lime and magnesia are soluble in alcohol<sup>2</sup>. This last circumstance might even give rise to a *fifth* source of error, as not only the muriate of soda, but also these earthy carbonates, were no doubt often mistaken for muriates.

#### CLASSIFICATION OF MINERAL WATERS.

Every attempt to reduce mineral waters to a purely systematic arrangement must be considered as purely artificial, as a mere matter of convenience, which originated in the desire to render them susceptible of ready comparison with each other as medicinal agents, upon

<sup>1</sup> *Berthollet*, *Statique Chim.* i. 496.—<sup>2</sup> *Grischow* in *Schweigger's Journal*, xxxiv. 261, Note.

the ascertaining a certain identity or similarity in their chemical constituents. As I have more than once had occasion to observe, Nature has traced no definite line of demarcation between their different groups, however distinctly characterized the extremes may seem to be. They cannot even be ranged in a linear series connected together by insensible gradations, because not unfrequently one spring unites the characters which belong to several classes, to each of which it is successively referred, according to the various views of different observers. The thermal springs of Karlsbad are one of the most striking instances of this uncertainty in the division of mineral springs. At one time they were ranged among the calcareous waters, at another they were thought more properly to belong to the chalybeate class, and now they have taken their place among the purging waters. Each of these views are in some degree correct, because each are founded upon different principles, and applicable to different topics of inquiry. To the geologist, if we keep out of view its high temperature, it presents most interest, as a calcareous water: he views in the vast tufaceous vault which incloses the boiling Sprudel the most important phenomenon connected with its history, and affording a striking example of the great changes thermal waters are in some cases capable of effecting in the physiognomy of the earth's surface. To the physician it is in all respects a chalybeate water: its quantity of iron is small, but it affords the only satisfactory explanation of the distinctly tonic effects which result from the long continued use of a spring so largely impregnated with sulphate of soda and other antiphlogistic salts; and, lastly, the chemist is entitled to consider it as a well marked instance of a purging water (Glauber-salzwasser), from the large quantity of Glauber salt it contains, and its predominance over every other constituent. The same uncertainty is equally applicable to the thermal waters of Bath, of Wiesbaden, of Teplitz, and many others, which have been thought at different periods, influenced no doubt very much by the fashionable medical and chemical philosophy of the age, to be chalybeate, purging, acidulous waters; and,



as a dernier resort as it were, have been at last considered to possess no virtues at all, or to exercise a certain mysterious influence, explicable upon no known principles. Indeed there are very few mineral waters which either chemically or medicinally present exclusively the characters or properties considered as peculiar to any single class. The predominant ingredient is, in almost every case, associated with a large proportion of other subordinate compounds; and often a comparatively minute constituent, or even one which is altogether imperceptible except by a very refined analysis, must decide its place in a medical arrangement.

All the attempts which have been hitherto made to classify mineral waters rest separately, or in combination, upon two principles;—the ingredients detected by analysis, and the thence inferred chemical constitution; or upon the medical virtues which have been ascribed to individual springs from actual experience, always, however, influenced very much by the prevalent ideas on physiology and therapeutics.

Paracelsus and the alchemists of that period divided mineral springs primarily, according to their temperature, into *hot* and *cold*. These were again distributed into subordinate classes, according as their principal ingredients were imagined to be salt, saltpetre, alum, sulphur, bitumen, iron, or other metals<sup>1</sup>.

A new era commences with the labours of Hoffmann, one of the chiefs of the medical triumvirate of the first half of the eighteenth century. An attempt was now made to reduce their constituents to fixed principles, to simplify the complexity of former divisions, and to form the basis of a pure chemical arrangement. A still more exclusively chemical method was traced out by the eminent analysts of the latter half of the eighteenth century, by Westrumb, Black, Fourcroy, &c. Black<sup>2</sup> divides all mineral waters into,—1. Thermal; 2. Acidulous; 3. Fos-

<sup>1</sup> A treatise is still extant of *Schwenckfeldt's*, entitled, *Instructio generalis de Aquis Mineralibus*, 1607, in which they are ranged under the heads of Salt, Saltpetre, Vitriol, Sulphur, Bitumen, Iron, Lead, Silver, Mercury, and Gold.

<sup>2</sup> Lectures on Chemistry, 1803, ii. 718.

sil alkaline; 4. Purging; 5. Chalybeate; 6. Sulphureous. Fourcroy's<sup>1</sup> is more complicated; he classes them under the heads of,—1. Cold acidulous; 2. Thermal acidulous; 3. Sulphuric saline; 4. Muriatic saline; 5. Simple sulphureous; 6. Sulphuretted gaseous; 7. Simple ferruginous; 8. Ferruginous and acidulous; 9. Sulphuric ferruginous.

About the beginning of the present century, it was seen that, however valuable and necessary for the chemist and naturalist an arrangement might be, founded upon their chemical relations alone, yet that it was not sufficient for the practical physician, who is called upon to consider them principally as *medicinal* agents. Besides our being by no means satisfactorily acquainted with the chemical constitution of not a few medicinal springs, it was seen that the effects of many were in direct opposition with what should have been inferred from their supposed composition; and experience demonstrated that very erroneous conclusions were often formed, by supposing certain virtues necessarily to accompany a certain composition. It was therefore endeavoured to combine the chemical and the medicinal properties of waters in their systematic distribution. Saunders, in his excellent Treatise<sup>2</sup>, divides them as follows: 1. Simple cold, *e.g.* Malvern; 2. Simple thermal, *e.g.* Buxton; 3. Simple saline, *e.g.* Seidlitz, the Sea; 4. Highly carbonated alkaline, *e.g.* Seltzer; 5. Simple carbonated chalybeate, *e.g.* Tunbridge; 6. Hot carbonated chalybeate, *e.g.* Bath; 7. Highly carbonated chalybeate, *e.g.* Pyrmont; 8. Saline carbonated chalybeate, *e.g.* Cheltenham; 9. Hot saline highly carbonated chalybeate, *e.g.* Karlsbad; 10. Vitriolated chalybeate, *e.g.* Hartfell; 11. Cold sulphureous, *e.g.* Harrowgate; 12. Hot alkaline sulphureous, *e.g.* Bareges. This very complicated classification was succeeded by one of a totally opposite character, remarkable for its simplicity and extreme generality; it is that recognised by Murray, Alibert, and the majority of late writers on the subject. They are all comprised under the four classes of,—1. Carbonated;

<sup>1</sup> Systeme des Connoissances Chimiques, iv. 301.—<sup>2</sup> On the Chemical History and Medical Powers of Mineral Waters, 1800, p. 362.

2. Sulphureous ; 3. Chalybeate ; 4. Saline. Indeed Murray observes<sup>1</sup>, that, to the chemist, “ all of them are either saline, or may be reduced under this division. From waters of the first class, the carbonic acid which is in excess is expelled by heat, and its quantity estimated. Sulphuretted hydrogen is in like manner expelled or decomposed ; and iron may be detected by its particular tests, and removed by appropriate methods. In all these cases the water remains with any saline impregnation, and of course is essentially the same in the subsequent steps of its analysis as a water purely saline.”

The last general division that I shall notice was proposed by the celebrated Hufeland<sup>2</sup>, and is that now adopted by most of his countrymen. It is based upon the principle that the real qualities and every classification of medicinal springs, must depend upon the union of their ascertained composition and their effects. It takes into account both the number and the nature of the constituents ; and does not forget that in many springs the quantity of gaseous and solid matter is so inconsiderable, that their effects can alone decide their medicinal rank. Hufeland considers it of importance to distinguish between the *general* and the *peculiar* character of a spring. The former is determined principally by the nature and quantity of the predominant constituent ; the latter by the subordinate ingredients, influenced by temperature and other external circumstances.

As the principal object of the present Essay is to consider mineral and thermal waters in relation to the general physics of the earth, were I inclined to offer to the attention of naturalists another arrangement of springs, I would probably recur, as the basis of arrangement, to the old division of the alchemists. Mineral waters would form as it were two parallel series, the *thermal* and the *cold*. Each of these might be divided into several subordinate heads, according to their predominant constituents in point of quantity. Such an arrangement would then assume some such form as the following :

<sup>1</sup> General Formula, &c. p. 263.—<sup>2</sup> Prakt. Übersicht der vorzüglichsten Heilq. Deutschlands, 1815-1820.



## SERIES I. THERMAL.

- CLASS 1. SULPHUREOUS. Predominant constituent, *Sulphuretted Hydrogen*:  
*e. g.* Bareges, Aix la Chapelle.
2. ALKALINE. Pred. const. *Carbonate of Soda*:  
*e. g.* Ems, Teplitz, Vichy, Mont d'Or, Ischia.
3. PURGING. Pred. const. *Sulphate of Soda*:  
*e. g.* Karlsbad, d'Aix, Pisa.
4. SALINE. Pred. const. *Muriate of Soda*:  
*e. g.* Wiesbaden, Bourbon l'Archambault, Civita Vecchia, Baden in Baden.
5. CALCAREOUS. Pred. const. *Carbonate*, or *Sulphate of Lime*:  
*e. g.* Bath, Buxton, St Allyre.
6. SILICEOUS. Pred. const. *Silica*:  
*e. g.* Geyser, Chaudes Aigues, Luxeuil, Mariara.
7. PURE. Little or no impregnation:  
*e. g.* Matlock, Vic en Carlates.

## SERIES II. COLD.

- CLASS 1. SULPHUREOUS. Predominant constituent, *Sulphuretted Hydrogen*:  
*e. g.* Harrowgate, Moffat, Nenndorff.
2. ACIDULOUS. Pred. const. *Carbonic Acid Gas*:  
*e. g.* Pymont, Selters, Asciano.
3. ALKALINE. Pred. const. *Carbonate of Soda*:  
*e. g.* Vals, Bilin, Malvern.
4. PURGING. Pred. const. *Sulphate of Soda*:  
*e. g.* Cheltenham, Franzensbad, Marienbad.
5. SALINE. Pred. const. *Muriate of Soda*:  
*e. g.* Leamington, Rennes, Bourbonne les Bains.
- (5.) BRINE SPRINGS. Sole const. *Muriate of Soda*:  
*e. g.* Ashby-de-la-Zouch, Kreuznach, Ischl, Bex.
6. CHALYBEATE. Pred. const. *Oxide of Iron*:  
*e. g.* Tunbridge, Spa.
7. ALUMINOUS CHALYBEATE. Pred. const. *Sulphates of Iron and Alumina*:  
*e. g.* Isle of Wight, Hartfell, Alexisbad.
8. BITTER. Pred. const. *Sulphate of Magnesia*:  
*e. g.* Salschütz, Seidlitz, Epsom.

This classification, however, is liable to no less serious objections than many of the preceding. In the first place, thermal and cold springs pass into one another by almost insensible gradations. What are usually denominated chalybeate waters, form an insuperable obstacle to any thing but a purely medicinal arrangement, because, with very few exceptions even in the strongest of the class, the quantity of iron is very small when compared with that of the other saline or gaseous constituents. I have introduced the calcareous and siliceous classes, from their importance in a geognostical point of view.

## SECTION IV.

### TEMPERATURE OF MINERAL SPRINGS.

THIS has a very extensive range, beginning almost at the freezing point and reaching up to the very boiling heat of water, or even beyond it. The temperature of a spring doubtless exercises a no less important influence upon the mutual reaction of the constituents than upon their effects on the human body, although these cannot, in most cases, be appreciated, from our ignorance of many of the laws of caloric, and more especially of its specific relations to different bodies.

I have formerly had occasion to notice the important effects of temperature upon carbonic acid gas, one of the most interesting and important of the constituents of springs. The uniformity in the effects of many thermal springs has also been one of the principal arguments brought forward by the advocates of the opinion, that all the ingredients of this class of waters are amalgamated into one whole. And certainly the elevation of temperature must exercise some peculiar influence upon the ingredients of hot springs, when we observe the facility of their assimilation in very weak states of the digestive organs, even when impregnated with a large quantity of highly debilitating salts.

In the present section will be considered only what go under the name of Hot or Thermal Waters, as the general causes of the temperature of all springs will come afterwards to be considered under the head of the Origin of Mineral Waters. A *thermal spring* may be defined to be one which possesses a temperature more or less elevated above the mean of the latitude or elevation at which it is situate, and the changes of which, if any, observe no regular periods coincident with the revolutions of the seasons.

In all ages, this class of bodies have been regarded with peculiar interest, often, however, owing to very different causes. In ancient times, when ignorance of the laws of nature and natural phenomena gave ample scope for the tyranny of priestcraft and superstition, their mysterious origin was regarded with sacred reverence. Subsequently, in the middle ages, the fancied antagonism between earth and fire rendered boiling springs gushing forth from the interior of the globe a phenomenon equally productive of astonishment. And it is only lately that the opinion of their possessing a greater capacity for caloric has begun to be appreciated according to its true value. Not less deeply do they excite the attentive meditations of the enlightened geologist of the present day from their connexion with the general question of the temperature of the globe, and with the local development of volcanic agency; he views them in fact in dernier analysis as the solfataras of an age anterior to the records of history.

Before entering into the enumeration of the principal thermal waters of the four continents, I may be allowed to dwell for a little upon two considerations of much importance connected with their temperature, viz. their supposed greater specific caloric, and the effect of carbonic acid alone in increasing their heat.

It was formerly an almost universal opinion, which is still pretty general, that natural thermal waters possessed a greater capacity for caloric than common water artificially raised to the same temperature. We may justly be surprised that a view so directly in opposition with



all the known laws of heat should ever have gained credence, not merely from the inspectors of the bathing establishments attached to mineral waters, but even from the medical superintendents and philosophers not a little versed in physical research. In the former, it might easily be ascribed to interested motives, and to the *charlatanerie* so common at these public places of resort. But as none of these causes can be considered with justice to operate in the latter case, we must endeavour to inquire a little into its origin, and the reasons upon which it was grounded. Longchamps<sup>1</sup> has found it a nearly universal maxim, at every one of all the numerous thermal waters which extend between the Pyrenees and the Vosges, that they require a longer time both to cool and to be raised to the boiling point than common water placed in the same circumstances<sup>2</sup>. The same opinion is equally prevalent at Karlsbad and the other hot springs which skirt the southern base of the Erzgebirge in the north of Bohemia. It was the opinion also of Hoffmann and all the older naturalists, and was doubtless in them not a little strengthened by the mysterious light in which every thing regarding warm springs was then wont to be regarded. Even yet it bears the sanction of the illustrious name of Kastner.

When we examine, however, the experiments and observations upon which the opinion is founded, their fallacy is immediately apparent. They have usually been made upon the water of enclosed baths or basins excluded from a free circulation of air, and where the water was constantly in contact with an atmosphere heated by radiation from its heated surface. The *Wildbad*, at Gastein in Salzburg, has been cited, among others, in support of the opinion, it being necessary to conduct the water (which only possesses a temperature of 113° F.) into the baths in the evening, in order that it may be cooled down to the bathing temperature by the morn-

<sup>1</sup> Sur la Chaleur des Eaux Thermales Naturelles, in the *Annales de Chim. et de Phys.* xxiv. 247.

<sup>2</sup> *Patissier* (u. s. p. 329) maintains that the thermal water of Bourbon l'Archambault is heated much slower when placed on the fire than other liquids.

ing. The long time, however, that is here necessary to lose a very few degrees of heat, is not surprising, when we reflect that a large mass of water enclosed in a stone bath can give off very little caloric, except by its upper surface, from the bad conducting power of its walls; and that, during the whole bathing-season, water of the above temperature is constantly in the bathing-chamber. There is no doubt that if common water, artificially heated to  $113^{\circ}$ , stood for the same time exposed to these conditions, its cooling would be equally slow.

Another opinion intimately connected with the preceding, and imagined to support the same views, must, I fear, abide the same fate, viz. that natural waters affect the feelings less than ordinary ones at the same temperature. The errors upon this point arose from men confounding with peculiarities in natural waters what they ought to have attributed to temperament, morbid sensibility, and many local circumstances, wholly unsusceptible of comparison with one another. To these causes must certainly be referred the facts which are given to us regarding some of the thermal waters in Switzerland, if there is really no fallacy in the statement. For instance, patients are stated to remain immersed for several hours together in the baths of Gastein, a fact scarcely credible. The same is affirmed of those of Leuk (temp.  $115\frac{1}{2}^{\circ}$  F.)<sup>1</sup>.

The true method of obtaining accurate results is obviously that of direct experiment, by exposing equal quantities of the water of springs, and of that artificially heated to the same degree, to similar circumstances of atmospheric temperature and moisture for the same space of time, and noting their comparative rates of cooling. When we consider, too, the important influence of its impregnation of solid and gaseous matters, in modifying the specific caloric of any liquid, in what intimate relations composition and temperature stand to each other; it is certain that, in every comparative experiment, a similarity of composition in the two fluids is an indispensable condition. It has, however, been often neglect-

<sup>1</sup> London Review, No. 2. May 1829, p. 322.

ed by chemical philosophers. This, accordingly, with all the accessory precautions, was the method employed by Longchamps in his experiments for the satisfactory determination of this question upon the waters of Bourbonne in France. He dissolved about 13 grammes of muriate of soda in the water which he selected for comparison, which is almost the equivalent of what Bosc and Bezu had found in their analysis of the Bourbonne water. He neglected the other ingredients subsequently detected by Duchanoy and Jurine. It is however worthy of remark, that the results were the same when simple distilled water was used. In all the three fluids, not only after the expiry of several hours, but at each successive interval, the temperature was exactly the same<sup>1</sup>. Salzer has found similar results from the baths of Baden<sup>2</sup>. Reuss, Damm, and Steinmann, have made

<sup>1</sup> It may interest the reader to obtain a tabular view of the results of these experiments :

## EXPERIMENT 1.

	0 h. 15'	1 h. 45'	3 h. 30'	7 h.	10 h.
Mineral Water,	46°.5 C	36.1	30.0	24.4	22.0
Saline Solution,	48 .1	36.7	30.2	24.4	22.0

## EXPERIMENT 2.

	0 h. 30'	3 h.	5 h.	8 h. 30'	10 h. 15'
Mineral Water,	49°.5 C	35.1	29.8	24.6	23.3
Ditto, No. 2,	50 .4	35.1	29.8	24.6	23.3
Distilled Water,	49 .5	34.9	29.7	24.6	23.3

In EXP. 1. Temp. of Room 21° at beginning, 19.1 at end.

... 2. ... 24 ... 21.7 ...

The water was in bottles which contained about  $2\frac{1}{2}$  pts., and the different strata were well mixed by agitation previous to each trial of temperature.

<sup>2</sup> Schweigger's Journal, ix. 180. The experiments were made with large glass bottles, one of which contained mineral water at the natural temperature of 149° F., and the other common well-water of the same heat. The thermometers suspended in each were observed every quarter of an hour : no inequality was observable in their rates of cooling, and, after twelve hours, both had reached the temperature of the surrounding air. The experiments were repeated in wood and earthenware vessels, and the same equality of temperature was constantly observed ; only that the times of cooling varied with the greater or less conducting power of the materials of the vessels, a case quite parallel to that of the baths of Gastein.



similar experiments at Karlsbad<sup>1</sup>, but they employed the water of the river Tepel, heated to 165° F., the temperature of the Sprudel, the gradual diminution of temperature was observed with very delicate thermometers, and the two fluids were found to require the same time to arrive at the temperature of the room, although it was remarked that the artificially heated water cooled at first faster than the Sprudel, which is perhaps to be attributed to the difference of composition of the two fluids. Ficus and Schweigger obtained the same results from the Teplitz water<sup>2</sup>. The same has been proved, by direct experiment, to hold true of many of the mineral waters of Switzerland. I need only cite those of Pagenstecher on the springs of Leuk and Weissenburg. We are however informed, that, on repeated experiments with the water of Pfeffers<sup>3</sup>, it cooled very rapidly down to the temperature of about 70° F.; but after that extremely slow, so that, on the expiry of twenty-four hours, it was still tepid, when common water previously heated to the same degree had become perfectly cold; as, however, the details of the process are not given, we cannot trace out the cause of this discrepancy.

Besides the spontaneous cooling of the water, the conducting power of mineral waters has been endeavoured to be ascertained by means of the calorimeter of Lavoisier and Laplace, and by the mixture of fluids of different temperatures. Not much reliance can, however, be placed on the calorimeter, an instrument which has been long distrusted by chemists as a measure of the specific caloric of bodies. And the beautiful researches of Dulong and Petit on the laws of heat, have shewn that the method by mixture requires the utmost precaution, in order to furnish correct results. It can only be employed when the heated bodies immersed in a cold fluid neither experience themselves nor produce any change in chemical constitution. This cannot, however,

<sup>1</sup> *Reuss* Marienbad, 1818, p. 172.—<sup>2</sup> *Struve*, üb. d. Nachbildung der Mineralwasser, pt. i. p. 39.—<sup>3</sup> *Rüsch* on the Mineral Waters of Switzerland, 1826, pt. ii. p. 15.

be the case when a mineral and pure water are mixed together, since the change thus effected, if there be any foundation for the preceding views of their composition, will amount to much more than a simple dilution.

Such were the methods employed by Kastner in his experiments on the thermal waters of Wiesbaden<sup>1</sup>, from which it has been concluded that these waters “cool much slower than pure water, or than a saline solution of the same specific gravity.” But even admitting that this mode of observation gave correct indications, it is impossible that the Wiesbad waters could differ so entirely from those of Bourbonne, Baden, Karlsbad, and Teplitz, regarding which the opposite has been so distinctly proved. The true source of the error is very obvious, from the experiments of Gmelin<sup>2</sup>, who found that the Kochbrunn at Wiesbad, distilled water, and artificial mineral water, heated to the same temperature, cooled in equal times when simply exposed to the air. We may therefore, from all these well-authenticated facts, consider, with Bischof<sup>3</sup>, the opinion lately revived, and become in some degree fashionable among his countrymen, that the caloric of thermal waters is of a peculiar character, as “a complete mystification.”

The next topic which demands our attention is the supposed effect of carbonic acid in elevating the temperature of springs, or, in other words, that acidulated waters are always some degrees warmer than ordinary springs without properly belonging to the thermal class.

This opinion was first distinctly stated by Von Buch; and he was led to form it by observing the temperature of some of the acidulous springs in the Canary Islands, some degrees higher than that of others in exactly the same circumstances of elevation, exposure, &c., but without this impregnation of carbonic acid. In one case, on the Island of Gran Canaria, there was a difference of 9° F., the common spring being 61° F., and a large, but weak, acidulous spring at no great distance from it, 70°<sup>4</sup>.

<sup>1</sup> Rüllmann, Wiesbad und seine Heilquellen, 1823, p. 120.—

<sup>2</sup> Poggendorff, Journal der Physik u. Chemie, vii. 464.—<sup>3</sup> E. Bischoff, in Hufeland's Journal, lviii. No. 5. p. 16.—<sup>4</sup> Physikalische Beschreibung der Canarischen Inseln, 1826, p. 85.

However singular the phenomenon may appear, this distinguished geologist is of opinion, that it is not peculiar to these islands, but pretty general, and even goes so far as to assert that he has found no acidulous spring, the temperature of which did not exceed that of common running springs<sup>1</sup>. Among the many hundred strong acidulous springs in the Wetterau, and between the Lahn and the Main, there is not one which is not some degrees higher than the ordinary temperature of cold springs. Selters, 800 feet above the level of the sea, is 61°.3 F. Gross Karben, between Friedberg and Frankfurt, one of the most impetuous and largest of known acidulous springs, is 59°. The favourable trials of the rock-salt on the Neckar having threatened the destruction of the salt work at Nauheim, in the same district, a shaft was sunk at the latter place in hopes that it might lead to a salt bed, as it was a large saline spring in secondary formations. From September to December 1822, a depth of 60 feet was attained, and the saline impregnation of the water had increased from  $2\frac{1}{2}$  to 3 per cent, its temperature was now 81°.5 F. In February 1823, the work had gone to a depth of 80 feet; there now appeared an immense quantity of water, at least 36000 cubic feet in twenty-four hours, the spring swelled up to within ten feet of the top of the shaft, the temperature had augmented to 80°, and the shaft became even dangerous from the quantity of carbonic acid which was disengaged, and stood more than a foot high, but the proportion of salt had not increased. Such are a few of the principal facts on which is founded the opinion of the effect of this gas in raising the temperature of springs.

Without calling in question these details which rest upon the authority of so eminent an observer, I think that I may venture to state that this is by no means universal with regard to all carbonated springs. Even Von Buch himself cites a strong acidulous spring in the Baranco de la Vergine on Gran Canaria, which was no

<sup>1</sup> Über Quellentemperatur in Poggendorff's Annalen d. Phys. u. Chem. xii. 415.



higher than  $66^{\circ}$ , while the two whose temperature was  $79^{\circ}$  and  $80^{\circ}$ , were only weakly impregnated with the gas. In October 1830, I found the temperature of the Karlsbad *Sauerling*, which disengages an immense volume of carbonic acid, to be only  $56^{\circ}$ <sup>1</sup>, which is very nearly the mean temperature of this latitude and elevation (1180 feet). And the mineral springs of Bilin, Franzensbad, and Marienbad in Bohemia, as well as those of Pyrmont, have all a temperature below  $55^{\circ}$  F., conjoined with a strong dose of carbonic acid. A very large proportion of the cold medicinal springs of Germany, many of which contain a greater or less quantity of the gas do not exceed  $50^{\circ}$ .

We must beware of confounding this effect of carbonic acid on the temperature of springs with the association often existing between cold acidulous and thermal waters, which will come to be considered under the head of the Position of Mineral Springs, and which depends upon other causes, and is connected with another class of phenomena.

With respect to the *degree* of temperature of springs, very different ideas have been attached at different times to the terms cold, warm, and hot springs. The freezing and boiling temperatures of water being taken as two fixed points, the temperature of the human body in the state of health was by common consent considered as an intermediate point,—the limit between hot and tepid waters. The cold bath was considered to range from  $32^{\circ}$ – $65^{\circ}$  F.; the tepid bath  $65^{\circ}$ – $82^{\circ}$ ; the warm bath  $85^{\circ}$ – $97^{\circ}$ ; the hot bath all above  $97^{\circ}$ <sup>2</sup>. A later division classes them under the heads of,—1. Cold,  $1^{\circ}$ – $65^{\circ}$  F.; 2. Cool,  $65^{\circ}$ – $77^{\circ}$ ; 3. Tepid,  $77^{\circ}$ – $88^{\circ}$ ; 4. Warm,  $88^{\circ}$ – $99^{\circ}$ ; 5. Hot,  $99^{\circ}$ – $212^{\circ}$ <sup>3</sup>. All these divisions are applicable only to thermal waters considered as therapeutical agents. Viewed in relation to the general economy of nature, they are altogether inapplicable. In the following enumeration, therefore, of those warm springs, the temperatures of which I have been able to collect, they will

<sup>1</sup> Temp. of Air,  $40^{\circ}$ .—<sup>2</sup> *Duncan's New Dispensatory*, 11th edit. 1826, p. 235.—<sup>3</sup> *Osann Darstellung*, p. 57.

be ranged according to their geographical position,—an arrangement which I conceive to possess the double advantage of being more easy of comparison with my subsequent inquiries into the Position of mineral and thermal waters, and of presenting more distinctly the lacunæ which exist in our acquaintance with this department of natural science.

## CONTINENT OF EUROPE.

*Portugal.*

Monchique in Algarves, . . . . .	86° F.	Link.
Tavira in ditto, . . . . .	78.5	Tavares.
Cabeco de Vide in Alentejo, . . . . .	81	Ditto.
Caldas da Rainhas, Estremadura, . . . . .	91	Link.
Cascães in ditto, . . . . .	84	Tavares.
Gaieiras in ditto, . . . . .	91	Ditto.
Leyria in ditto, . . . . .	77	Ditto.
Baños do Duque in ditto, . . . . .	86	Ditto.
Miorga in ditto, . . . . .	82	Ditto.
Monte Real in ditto, . . . . .	66	Ditto.
Povea de Coz in ditto, . . . . .	77	Ditto.
Rio Real in ditto, . . . . .	75	Ditto.
Torres Vedras in ditto, . . . . .	111	Ditto.
Aqua Santa de Vimeiro, . . . . .	79	Ditto.
Alcafeche in Beira, . . . . .	99	Ditto.
Aregos in ditto, . . . . .	142	Ditto.
Canas de Senhorin in ditto, . . . . .	93	Ditto.
Carvalhal in ditto, . . . . .	99	Ditto.
Santa Gemil in ditto, . . . . .	120	Ditto.
San Pedro Dosal in ditto, . . . . .	154	Ditto.
Penagareia in ditto, . . . . .	68	Ditto.
Prunto, Coimbra in ditto, . . . . .	90	Ditto.
Penamacon in ditto, . . . . .	68	Ditto.
Ranhados in ditto, . . . . .	108	Ditto.
Rapoila de Coa in ditto, . . . . .	99	Ditto.
Unhaes da Sarra in ditto, . . . . .	88	Ditto.
Caldas das Taipas in Miño, . . . . .	91	Ditto.
Caldellas de Rendusa in ditto, . . . . .	89	Ditto.
Canavares in ditto, . . . . .	93	Ditto.
Gerez in ditto, . . . . .	144	Ditto (122° Link).
Guimarens in ditto, . . . . .	138	Ditto.
Monçao in ditto, . . . . .	111	Ditto.
Caldas de Favaio in Tra Los Montes, . . . . .	91	Ditto.
Chaves in ditto, . . . . .	142	Ditto.
Pombal d'Avicaes in ditto, . . . . .	95	Ditto.
Ponte de Cavez in ditto, . . . . .	75	Ditto.
Rede de Convaceira in ditto, . . . . .	99	Ditto.

*Spain.*

Carratraca in Granada, . . . . .	66	Alibert.
Buzot in Valencia, . . . . .	104	Laborde,

*France.*

Cambo in the Pyrenees, . . .	70° F.	Palassou,
Eaux Bonnes in ditto, . . .	93	Poumier.
Bareges in ditto, . . .	122	Palassou <sup>1</sup> .
Bagneres de Luchon in ditto, . . .	145	Ditto.
Dax in ditto, . . .	181	Ditto.
Oletta in ditto, . . .	190	Ditto.
St Sauveur in ditto, . . .	93	Alibert.
Cauterets in ditto, . . .	122	Lüdemann.
Ussat in ditto, . . .	102	Figuier.
Audinac in ditto, . . .	73	Alibert.
Cap Bern in ditto, . . .	88	Ditto.
Encausse in ditto, . . .	66	Ditto.
Rennes les Bains in Dep. l'Aude, . . .	124	Julia and Reboul,
Aix in Provence, . . .	93	Alibert,
Balaruc in Dep. l'Herault, . . .	120	Figuier.
Avene in ditto, . . .	84	Alibert.
St Laurent les Bains in Dep. l'-		
Ardeche, . . .	122	Ditto.
Sylvanes in Dep. l'Aveyron, . . .	104	Ditto.
Cranzac in ditto, . . .	108	Brongniart.
Bagnols in Dep. Lozere, . . .	113	Alibert.
Greoulx in Dep. Lower Alps, . . .	102	Ditto.
Digne in ditto, . . .	104	Valentin.
Chaudes Aigues, Dep. du Cantal, . . .	190	Berthier.
Vic in ditto, . . .	212 <sup>2</sup>	Brongniart.
Mont d'Or, Dep. Puy de Dome, . . .	113	Bertrand.
St Nectaire in ditto, . . .	100	Boullay.
Clermont in ditto, . . .	88	Alibert.
Chateau Neuf in ditto, . . .	102	Ditto.
Chatel Guyon in ditto, . . .	86	Cadet.
St Mart in ditto, . . .	82	Alibert.
Vichy in Dep. de l'Allier, . . .	115	Longchamps,
Bourbon l'Archambault in ditto, . . .	140	Alibert.
Neris in ditto, . . .	129	Longchamps.
La Motte in Dep. l'Isere, . . .	183	Alibert.
Evaux in Dep. la Creuse, . . .	133	Ditto.
St Honoré in Mts. of Morvan, . . .	91	Vauquelin,
Bourbon Lancy in Dep. Saone		
and Loire, . . .	140	Jaquemont,
Luxeuil in Dep. Haute Saone, . . .	108	Alibert.
Bourbonne les Bains in Dep.		
Haute Marne, . . .	156	Ditto.
Plombieres in Dep. des Vosges, . . .	154	Vauquelin.
Bains in ditto, . . .	151	Alibert.
Bagnoles in Dep. de l'Orn, . . .	79	Vauquelin,
Bilazai, . . .	77	Osann.
Vinca, . . .	77	Ditto.
Foncaude, . . .	77	Ditto.
Fonsanges, . . .	77	Ditto.
De la Bastide, . . .	77	Ditto.
Caudies, . . .	82	Lüdemann,

<sup>1</sup> When there are several springs at one place, the temperature of the hottest that quoted.



Gaynoles, . . . . .	82° F.	Lüdemann.
Alet, . . . . .	82	Ditto.
Campagne, . . . . .	82	Ditto.
Sail, . . . . .	84	Osann.
Castra Vivent, . . . . .	84	Ditto.
Saubuse, . . . . .	88	Ditto.
Riviere, . . . . .	88	Ditto.
Llo, . . . . .	91	Ditto.
Malou, . . . . .	97	Ditto.
Barbautan, . . . . .	104	Ditto.
Tercis, . . . . .	106	Ditto.
Bourboule, . . . . .	118	Ditto.
La Preste, . . . . .	119	Ditto.
Prechac, . . . . .	129	Ditto.
Vernet, . . . . .	160	Lüdemann.
Carcaniere, . . . . .	158	Ditto.
Arles, . . . . .	160	Ditto.

*Switzerland, Tyrol, Styria.*

St Gervais in Savoy, . . . . .	113° F.	De la Rive.
Aix in ditto, . . . . .	120	Alibert.
Perriere, near Moutiers in Savoy, . . . . .	100	Socquet.
Baden in Canton Aargau, . . . . .	115	Bauhof.
Schinznach in ditto, . . . . .	91	Peschier.
Weissenburg in C. Bern, . . . . .	84	Brunner.
Leuk in C. Wallis, . . . . .	124	Ebel.
Pfeffers in C. St Gallen, . . . . .	100	Capeller.
Bormio in the Veltlin, . . . . .	104	Demagri.
Masinobad in ditto, . . . . .	93	Ditto.
Vals in C. Grisons, . . . . .	79	Capeller.
Courmayeur, near St Didier in Piedmont, . . . . .	93	Bakewell.
Naters in C. Wallis, . . . . .	86	Ditto.
Gastein in Salzburg, . . . . .	122	Osann.
Neuhaus in Styria, . . . . .	97	Schallgruber.
Tyffer in ditto, . . . . .	98	Macher.
Töplitz in ditto, . . . . .	113	Osann.
Baden in Lower Austria, . . . . .	100	Schenk.

*Germany.*

St Amand in Netherlands, . . . . .	80° F.	Longchamps.
Aix la Chapelle in Lower Rhine, . . . . .	136	Monheim.
Burtscheid in ditto, . . . . .	172	Ditto.
Bertrich in ditto, . . . . .	91	Bischof.
Lauterbach in ditto, . . . . .	82	Osann.
Wiesbaden in Nassau, . . . . .	158	Kastner.
Ems in ditto, . . . . .	122	Ditto.
Schlangenbad in ditto, . . . . .	86	Ditto.
Baden in Baden, . . . . .	154	Osann.
Huberbad in ditto, . . . . .	84	Schütz.
Badenweiler in ditto, . . . . .	77	Osann.
Wildbad in Württemberg, . . . . .	95	Kerner.
Wolkenstein in Saxony, . . . . .	86	Kühn.
Wiesbaden in ditto, . . . . .	70	Osann.

Karlsbad Sprudel in Bohemia,	165° F.	Reuss, 1812 <sup>1</sup> .
Teplitz in ditto, . . . .	121	Osann <sup>2</sup> .
Warmbrunn in Silesia, . . .	100	Ditto.
Landeck in County of Glatz,	86	Ditto.
Vatz in Transylvania, . . .	88	Patacki.
Barangy in Hungary, . . . .	124	Osann.
Warasdin in ditto, . . . .	136	Ditto.
Piestan in ditto, . . . .	142	Wallich.
Buda in ditto, . . . .	147	Osann <sup>3</sup> .
Mehadia in ditto, . . . .	118	Ditto.
Topusco in Slavonia, . . . .	142	Ditto.

*Italy.*

Valdieri in Piedmont, . . . .	147° F.	Bertini.
Vinadio in ditto, . . . .	154	Ditto.
Acqua Santa in ditto, . . . .	77	Giobert.
Roccabigliera in ditto, . . .	82	Foderé.
Perriere in ditto, . . . .	100	Osann.
Craveggia in ditto, . . . .	82	Ragazzoni.
St Lucia in ditto, . . . .	95	Giobert.
Magnesia in ditto, . . . .	104	Ditto.
Abano in Lombardy, . . . .	181	Osann.
Acqui in ditto, . . . .	124	Moyon.
Caldiero in ditto, . . . .	79	Paganini.
St Pellegrino in ditto, . . . .	84	Carrara.
Volterra in Tuscany, . . . .	115	Osann.
Pisa in ditto, . . . .	106	Valentin.
Lucca in ditto, . . . .	129	Moscheni.
Montecatini in ditto, . . . .	97	Bicheraï.
Casciano in ditto, . . . .	113	Osann.
Porretta in Papal States, . . .	102	Bassi.
Civita Vecchia in ditto, . . .	86	Morichini.
Pozzuoli in Naples, . . . .	111	Paganini.
Contursi in ditto, . . . .	95	Paganini.
Castellamare in ditto, . . . .	104	Andria.
Piscarelli in ditto, . . . .	200	Bischof.
Spezia, . . . .	84	Paganini.

*Greece.*

Thermopylæ, . . . .	113° F.	Clarke.
---------------------	---------	---------

## EUROPEAN ISLANDS.

Rycum in Iceland, . . . .	212° F.	Stanley <sup>4</sup> .
New Geyser in ditto, . . . .	212	Ditto.
Old Geyser in ditto, . . . .	200	Ditto.
Buxton in England,] . . . .	82	Saunders.
Matlock in ditto, . . . .	68	Scudamore.
North Bradwell in ditto, . . .	58	Daubeny.
Stony Middleton in ditto, . . .	64	Ditto.
Bristol in ditto, . . . .	74	Saunders.

<sup>1</sup> Becher, in 1789, 165°, at times 167°. Klaproth, in 1793, 157°. M. G., 1830, Hygeia's spring 159°, hottest of the whole.

<sup>2</sup> Ambrozzi, in 1797, 117°.5. M. G., 1830, 115°.

<sup>3</sup> 133°, Beudant, (Voyage en Hongrie, ii. 393.)

<sup>4</sup> Mr Wright once observed 213°. (Edin. Phil. Trans. iii. 127.)

Bath in ditto (Hot bath)	. . .	117° F.	Philips.
Mallow in Ireland,	. . .	69	Rutty.
Guitera in Corsica,	. . .	122	Peraldi.
Guagno in ditto,	. . .	118	Osann.
Fordingianu in Sardinia,	. . .	122	Tabasso.
Coquinas in ditto,	. . .	159	Smyth.
Acqua Cotta in ditto,	. . .	105	Ditto.
Benetutti in ditto,	. . .	100	Bertini.
Sardara in ditto,	. . .	111	Rolando <sup>1</sup> .
Island of Milo,	. . .	140	Darwin.
Gurgitello in Ischia,	. . .	167	Giudice <sup>2</sup> .
Acqua San Restituta in ditto,	. . .	126	Ditto <sup>3</sup> .
Olmitello in ditto,	. . .	117	Ditto.
Delle Petrelle in ditto,	. . .	212	Siano.

## CONTINENT OF ASIA.

Lidja Hamam in Asia Minor,	142° F.	Clarke.
Tiberias in Syria,	200	Madden.
Elizabeth spring in the Caucasus,	84	Neljubin.
Kalmuck spring in ditto,	88	Ditto.
Nicolai spring in ditto,	100	Ditto.
Eisenberg in ditto,	106	Ditto <sup>4</sup> .
Mount Maschuka in ditto,	115	Ditto <sup>5</sup> .
Terek in ditto,	192	Güldenstädt.
Marienbad in ditto,	109	Neljubin.
Kumgara in ditto,	87	Hermann.
Katherinenquellen in ditto,	190	Ditto.
Paulsquellen in ditto,	165	Ditto.
Petersquellen in ditto,	195	Ditto.
Turkinsk at Lake Baikal,	127	Rehmann.
Frelicka at ditto,	154	Georgi.
Kotelnikowa at ditto,	156	Ditto.
Bargusinsk at ditto,	167	Rehmann.
Budrenaut in the Himalayah,	139	Traill.
Schoahou in Tibet,	191	Turner.
Gangamaar in ditto,	88	Ditto.
Monghyr in Hindostan,	140	Herbert.
Sirgoojah in ditto,	185	Breton.
Trinquemala in ditto,	124	Osann.
Sonah near Delhi,	108	Ditto.

## ASIATIC ISLANDS.

Cannea, near Trincomalie, in Ceylon,	107° F.	Davy.
Badulla, Upper Ouva, in ditto, (1860 feet),	76	Ditto.
Alipoota in ditto,	80	Ditto.
Island of Amsterdam,	212	Barrow.
Cheribon in Java,	130	Raffles.
Saline springs on south side of do.	130	

<sup>1</sup> 139°. (Smyth).<sup>2</sup> The temperature rises about 45° between the beginning of spring and the middle of summer; and the general belief is, that it ranges about 122° at the former and 167° at the latter period. Wenzl, in Medicinisch Chirurg. Zeitung., Sept. 1830.<sup>3</sup> When previously agitated; when not disturbed 84°.<sup>4</sup> 103°. (Hermann).<sup>5</sup> Alexander's spring, 118°; Warwazi spring, 87°. (Hermann).



Unsen in Japan, . . .	212° F.	Kæmpfer.
Doogoos in Tanna, . . .	191	Alibert.
Another in ditto, . . .	101	Ditto.

## CONTINENT OF AFRICA.

Cardouw ridge in Caffraria, . . .	108° F.	Barrow.
Graaf Reynet, banks of Fish River, in ditto, . . .	88	Ditto.
Brand Valley in ditto, . . .	144	Ditto.
Zwarteberg in ditto, . . .	118	Ditto.

## AFRICAN ISLANDS.

St Michael in the Azores, . . .	208° F.	Webster.
Mont Salazes in Isle of Bourbon, . . .	86	Alibert.

## CONTINENT OF NORTH AMERICA.

Buncombe in North Carolina, . . .	104° F.	Warden.
Ouachitta in Territory of Arkansas, . . .	150	Ditto.
At the sources of the James' River, . . .	112	Ditto.
Chichimaquillo in Mexico, . . .	205	Humboldt.
Comangillas, near Guanaxuato, in Mexico, . . .	205	Ditto.

## CONTINENT OF SOUTH AMERICA.

Onoto in Cordillera of Venezuela, . . .	112° F.	Boussingault.
Mariara in ditto, near Portocabello, . . .	147	Ditto <sup>1</sup> .
Brigantin, near New Barcelona, . . .	110	Humboldt.
Trincheras in Valleys of Aragua, near Portocabello, . . .	195	Ditto.
New Barcelona, . . .	109	Ditto.
Near St Jago, . . .	140	Osann.
Provisor in New Barcelona, . . .	149	Boussingault.
Cuença (Lat. 2° 53' S.), . . .	162	Humboldt.
Tollacpoma, near Caxamarca, . . .	156	Ditto.
San Juan, . . .	88	Ditto.

## AMERICAN ISLANDS.

St Lucia, valley N.E. of Soufriere, . . .	203° F.	Alibert.
Martinique, at Fort Royal, . . .	122	Ditto.
Guadeloupe in Ravine Chaude, . . .	149	Ditto.
... Eaux de Dole, . . .	102	Ditto.
... Eaux Bouillantes, . . .	131	Ditto.
Near Charleston in Nevis, . . .	106	Ditto.
De la Cabouane in Hayti, . . .	100	St Mery.
Parish of Dalmarie in ditto, . . .	145	Ditto.
Eaux de Banique in ditto, . . .	84	Ditto.
Boines in ditto, . . .	127	Osann.
St Thomas in Jamaica, . . .	123	Alibert.
St Diego in Cuba, . . .	95	Sanchez Rubio.

<sup>1</sup> 138°. Humboldt, (Pers. Narr. vi. 489; 1826, Eng. Trans.)

## SECTION V.

## COMPARISON OF MINERAL SPRINGS WITH OTHER WATERS.

ALTHOUGH there exist numerous transitions between mineral and other waters, they are distinguished from one another by several important circumstances in their composition. Generally speaking, they contain a much less quantity of foreign constituents, are more dependent on external influences, and consequently subject to greater changes in composition, temperature, quantity, &c.

## I. TERRESTRIAL WATERS.

THE peculiar qualities of these waters most frequently depend upon the nature of the rocky strata with which they come in contact in the process of their formation. These may contain a greater or less quantity of soluble matters or of organic remains capable of being taken up by their percolating menstruum. To these, more than to mineral waters properly so called, is applicable the often quoted passage of Pliny: "*Tales sunt aquæ qualis est terra per quam fluunt*<sup>1</sup>." These waters are derived proximately from the invisible aqueous vapours suspended in the atmosphere, or enveloping the summits of the high lands in the form of clouds and fogs, in part from rain and other aqueous meteors, but their ultimate source is in the great reservoirs of the ocean. A few perhaps have their source deeper in the bowels of the earth. "Thus," says Dr Halley, "is one part of the vapours blown upon the land returned by the rivers to the sea from whence they came; another part falls in dews and rains again into the sea before reaching land, because of the great extent of the ocean. A third part falls on the lower lands, and is the pabulum of plants, where it does not rest but is again exhaled. After several vicissitudes

<sup>1</sup> Hist. Natur. xxxi. 29.

of rising in vapour and falling in dews or rain, each particle of the water is at last returned to the sea from whence it came. After this manner is the circulation performed, and I doubt not but this hypothesis is more reasonable than that of those who derive all springs from rain water or from filtration of sea waters through tubes of earth<sup>1</sup>.”

I shall now proceed very briefly to trace the changes and modifications experienced by terrestrial waters from their first appearance in the form of springs, through their union into rivers, their collection into lakes, and their final termination in the great receptacle and centre of union of all waters,—the ocean itself.

Witting states the specific gravity of common springs, rivers and lakes, never to exceed 1002.9<sup>2</sup>.

1. *Common Springs*.—These form the connecting link between ordinary waters and mineral springs. Whatever may be the secret processes which preside over their origin, their foreign ingredients are derived immediately from the soil out of which they issue. When they flow from a sandy or siliceous matrix they are purest of all ; but when they issue from limestone, rock-salt formations, or from a boggy soil, they generally contain a certain proportion of earthy, saline, or organic matters, and even of the oxide of iron, and form the true passage into mineral waters. From these, however, they are distinguished by an inferior specific gravity, their changeable temperature, and their being more easily affected by atmospheric phenomena, as weather and season.

Their specific gravity is however greater than that of other terrestrial waters with the exception of the sea. The quantity of solid matters which they hold in solution depends very much upon their temperature, and their greater or less exposure to the air. A low temperature enables them to hold in solution a much larger quantity than usual of carbonic acid, and consequently to take up

<sup>1</sup> Phil. Trans. xvii. 463.—<sup>2</sup> Brandes Archiv, xi. 223.



a larger dose of the carbonate and sulphate of lime, the carbonate of magnesia, the oxide of iron, and other insoluble earths. Frequent agitation and contact with the air disengages the carbonic acid, and precipitates these salts in the channel over which they flow. Well water, therefore, presents all their characters in the most perfect degree, and on the other hand they pass gradually into river water.

Founded upon these differences the vulgar have in all ages formed a capital division of spring waters into *hard* and *soft*. Hard waters, which contain a greater or less proportion of the carbonate and sulphate of lime, are characterised by decomposing a solution of soap, the oil forming an insoluble precipitate with the base of the earthy salt. When boiled they become turbid, and yield a whitish deposit. A greater or less milkiness, even amounting to a precipitate, is accordingly produced on adding to most well waters solutions of the nitrate of silver, nitrate of barytes, oxalate of ammonia, and lime water. Soft waters, again, whether of springs, rivers, or lakes, from their long exposure to the air, contain little carbonic acid or earthy salts, and when they flow through marshy beds, or over a considerable tract of vegetable earth, they contain a certain proportion of organic matter. Their character is not to precipitate a solution of soap, although a great number are affected by the above reagents. Many attempts have been made to determine our ideas of the hardness or the softness of a water by precise numerical data. These being mostly arbitrary, it is not surprising that different standards should have been assumed at different times. Falconer says, that a hard water may contain in a pound from 5–16 grains of solid matter. Haller<sup>1</sup> maintains that, if a water contains more than 5 grains it ceases to be a soft water. And Saunders fixes at the same quantity the minimum of a hard water<sup>2</sup>.

Hippocrates has long ago remarked the important effects, which an acute observer may detect, in the physi-

<sup>1</sup> Element. Physiolog. iii. 230.—<sup>2</sup> On Mineral Waters, p. 76.

cal constitution of the inhabitants of a country, and in their liability to certain diseases which are referable to the waters in common use from domestic purposes. And although the progress of luxury and the refinements of civilization tend invariably to neutralize and to counteract the tendencies of nature, modern observations would still shew that this is an important object of medical police. A large proportion of lime in common springs has often been thought to be a cause of some endemic diseases. Percival and Lister ascribe to this cause the prevalence of calculus in some districts<sup>1</sup>. The water of Rheims was long thought to be the principal reason of the frequency of scrofula and other glandular diseases in that town; the inhabitants then made use only of what was procured from wells. After a machine was constructed which brought the water from a neighbouring river, the number of patients was in the space of thirty years reduced to one-half of what it had formerly been, so that an hospital which had been maintained for the sole purpose of curing these diseases, was considered nearly unnecessary<sup>2</sup>. We are informed that in those districts of Franconia, where scrofulous diseases are endemic, and cretinism very common, the spring water contains so much sulphate of lime, that it can neither be used for boiling vegetables nor for washing<sup>3</sup>. Coindet has observed that the water in the lower part of the town of Geneva, has a great tendency to produce scrofulous disorders, and that the young recruits are particularly liable to be affected by it; and as a proof that it is ascribable to the water alone, a mere change of it is sufficient to restore them to their former health. Georgi also remarks that the same disorders very commonly follow the use of the Lena water in Siberia, and are removed by drinking only of the river Rutschei<sup>4</sup>.

These observations are sufficient to illustrate the importance of attending to the qualities of the waters used

<sup>1</sup> *Lister de Calculo*, p. 36.—<sup>2</sup> *Heberden's Commentaries*, chap. 87; *de Struma*.—<sup>3</sup> *Sensburg, Der Cretinismus des Königreichs Baiern*, 1825; p. 56.—<sup>4</sup> *Frank, System einer Vollst. Med. Polizei*, pt. iii. p. 384.

by large communities, both in a natural history and medicinal point of view. According to Heberden, the well water of London contains different sulphates, muriates and nitrates, principally of lime. The well water of Paris, which flows directly from a calcareous soil, and is remarkable for the proximity of great masses of gypsum, does not differ in composition from the waters of the Seine, but only contains a much larger proportion of foreign contents. In both, we find sulphates, muriates, and carbonates of the earths and alkalies, even the nitrate of potash and carbonate of ammonia are mentioned, which are probably owing to vegetable and animal matters, in a state of decomposition. Rose's researches have shewn the common wells of Berlin to contain from 3 to 11.5 grains of solid matter in a pound of water, consisting of carbonate of lime, muriate of soda, sulphate of magnesia, nitrate of potash, with a very small proportion of the sulphate of lime<sup>1</sup>. Vogel obtained a brownish residuum from the spring water at Munich, which contained nitrate of potash, sulphate and muriate of soda, muriate and carbonate of magnesia, carbonate and sulphate of lime, and carbonate of iron<sup>2</sup>. The drinking water of Stockholm contains, besides a large proportion of nitrates, muriate of soda, sulphate of lime and potash, carbonate of lime and magnesia, oxide of iron, silica and extractive<sup>3</sup>. The water of a pump-well at Kiel used as good drinking water was found by Pfaff to yield 9 grains in a pound, consisting of carbonates, muriates, sulphates, and of silica. The waters of Leipzig, Warsaw, and Augsburg, have all been found to contain a certain proportion of foreign matters.

It is obvious that it would require a very small augmentation in the impregnation of these waters, to convert them into true mineral springs.

2. *River Water*.—Deriving its origin generally from spring and rain water, it holds an intermediate place be-

<sup>1</sup> *Formey*, Versuch einer Topographie v. Berlin 1796, p. 22.—

<sup>2</sup> *Kastner's Archiv*, v. 497.—<sup>3</sup> *Berzelius* in *Neues Journ. f. Chem. u. Physik*, 1811; ii. No. 4.



tween these two. It contains less carbonic acid and earthy salts, but often holds in suspension minute particles of sand, vegetables in a state of decomposition, and other impurities, which are all separated by rest or filtration. Those rivers which are subject to periodical inundations, are chiefly remarkable for these impurities, which they take up in their progress over the rich and cultivated soil on their banks: I need only cite the vast Mississippi, the Po, and the Nile. The latter, which still retains the character for salubrity, for which it was celebrated in the days of Prosper Alpinus, is very remarkable for its turbidity, which is, however, entirely removed by spontaneous deposition<sup>1</sup>. The Thames holds in suspension a quantity of mud and animal and vegetable exuviae, which render it before their removal by rest or filtration, very prone to putrefaction<sup>2</sup>. The water of the Seine at Paris, holds in true solution about 5 grains of solid matter in a pound, which consist of sulphate of lime, muriate of soda, and nitrate of potash<sup>3</sup>. A pound of the Pader water near Paderborn, yielded 3.5 gr. of muriate of soda; 2.5 gr. carbonate of lime; 0.5 gr. carbonate of magnesia; 0.5 gr. sulphate of lime; and 0.5 gr. muriate of lime<sup>4</sup>. Wetzler maintains that many of the rivers in the south of Germany, contain carbonate of soda, as the Danube, the Lech, the Günz, &c.<sup>5</sup>. Those rivers, again, in mountainous districts, which flow rapidly, and with much agitation over a rocky bed, are remarkable for their extreme purity. This is the case with the waters of the Dee in England, (Saunders); of many of the northern provinces of Sweden, (Berzelius); of Switzerland and the Tyrol, (Haller).

The colour of rivers, which varies very much in different countries, and has sometimes been thought to characterise those of particular districts, does not depend so much on the composition of the water, as on the nature of its bed, and the reflection of light from its banks.

<sup>1</sup> *Savary*, *Lettres sur l'Egypte*, 1798; ii. 179, iii. 3.—<sup>2</sup> *Saunders* on *Mineral Waters*, p. 73.—<sup>3</sup> *Parmentier* in *Jour. de Phys.* 1775.—

<sup>4</sup> *Witting* in *Brandes Archiv.* xiv. 184.—<sup>5</sup> *Kastner's Archiv*; x. 322, xi. 125.

The composition of river water, therefore, depends on its mode of origin, its velocity, the length of its course, the nature of its bed. Many of the rivers of volcanic districts are remarkable for their impregnation with free sulphuric and muriatic acids, and different sulphates and muriates; such as the river in Java, observed by Leschenault, and the Rio Vinagre, which issues from the volcano of Purace in South America, (see p. 35). All the rivers, however, of which we have any account, fall far short of the Sagis, which flows through the Kirghis steppes, which contains, according to the analysis of Hess, in 10,000 pts. 859 of solid matters, consisting of 705.9 muriate of soda, 39.4 muriate of magnesia, 45.1 muriate of lime, and 68.4 sulphate of soda<sup>1</sup>.

3. *Lake Water*.—Most lakes being formed by the influx of springs, rivers, and rain water, present a combination of the characters of each. Although they present a great surface of contact to the air, their evaporation is supplied, and the equilibrium of their composition maintained, by the continual accession of fresh water, from the above sources. They are generally very limpid, as the state of continual rest permits of the deposition of all the particles of mud which may be held in suspension, the effects of atmospheric agitations extending but a very little way below the surface.

Small pools in marshy districts, however, are generally very impure. Being in continual contact with a soil charged with vegetable and animal matters in a state of decomposition, they frequently contain a considerable proportion of organic matters. Their shallowness favouring the process of evaporation, and an elevation of temperature, from the contact of the sun's rays, they are particularly favourable to the development of organic forms,—both plants and animals.

Strikingly contrasted with these are the examples of lakes situate in countries which abound in saline efflorescences on the surface of the soil. They hold in solu-

<sup>1</sup> *Berzelius*, Discourse on the Progress of the Physical Sciences, 1829; p. 238.

tion a large quantity of solid matters, and form the true transition from the terrestrial waters that we have been considering to the general receptacle of all,—the ocean. Considerable uniformity and simplicity of composition characterize these lakes. The principal foreign constituents are the muriate of soda, the carbonate of soda, and the subborate of the same base. Sulphur lakes exist near Volterra in Tuscany. Their predominant constituents are always determined by the nature of the soil which forms their basins. Salt lakes are very abundant in the south of Russia, in the steppes which stand in connexion with the great Asiatic depression, the centre of which is occupied by the Caspian,—itself nothing but a vast salt lake<sup>1</sup>: here we have the lakes of Elton, Bogda, Sacker, and many others. The Dead Sea is unique in the history of this class of waters, presenting an example of a great salt lake in the midst of a mountainous district, and sheltered very much from the full action of the sun's rays. It contains, according to Klaproth, 42.6 per cent. of saline matter, consisting of 24.2 of muriate of magnesia, 10.6 muriate of lime, and 7.8 of muriate of soda. This chemist found its specific gravity to be 1245<sup>2</sup>.

<sup>1</sup> I am not aware that the water of the Caspian has been specially analyzed. It would be highly interesting to ascertain precisely if it contain more saline matter than the Mediterranean,—itself salter than the general mass of the ocean.

<sup>2</sup> Klaproth *Beiträge* 1810, v. 185. His analysis was performed on water brought from the East by the Abbé Mariti. It is probably the most correct view of its composition, from its close accordance with that of Macquer and Lavoisier (*Mem. de l'Acad. des Sciences*, 1778, p. 69.), although it differs very considerably from that of Dr Marcet (*Phil. Trans.* for 1807, p. 296.). The French chemists found its specific gravity to be 1240.3; that it contained 44.4 per cent. of saline matter, 38.15 of which were muriates of lime and magnesia, and 6.25 the muriate of soda. Marcet found its specific gravity 1211; that it contained 24.6 per cent. of solid matter, 10.2 of which were muriate of magnesia, 10.4 muriate of soda, 3.9 muriate of lime, and 0.05 sulphate of lime. This difference may perhaps be owing to the latter specimen having been taken from the lake not far from the influx of the Jordan. It, however, agrees more nearly with that of Gay-Lussac (*Annales de Chimie*, xi. 195.) who found a specimen which had been brought to Europe in a vessel of tinned iron, hermetically closed, to possess a specific gravity of 1228.3, and to contain 26.24 per cent. of saline matter, consisting of 6.95 muriate of soda, 3.98 muriate of lime, and 15.31 muriate of magnesia.



Natron and borax are principally met with in the lakes of Hungary, Egypt, Persia, Tibet, and South America.

4. *Sea Water*.—This is still farther removed from a state of purity than any of the preceding. Not to mention the muddy particles which it frequently holds in suspension, particularly in certain localities, such as near the mouths of large rivers; and the numerous organic substances which must result from the presence of the prodigious number of animals and vegetables with which it every where abounds,—it far exceeds ordinary waters, and even the greater part of true mineral waters, in the quantity of saline substances which it holds in a state of perfect solution. The increasing perfection of analysis in modern times, has revealed the existence of many substances, as potash, iodine, and bromine, whose presence was never before suspected. Indeed, it might be supposed that sea water should contain a portion of all the soluble matters in the globe, since it is the common receptacle for all the rivers and springs which traverse its surface, or which have come from its interior. Its quantity of solid matters differs very much in different seas, and chemists have given very various views both of the ingredients that it contains, and of the proportion which these bear to each other.

Lavoisier assigns the following proportions<sup>1</sup> in 10,000 parts:—136.8 muriate of soda; 16.0 muriate of magnesia; 24.9 muriate of lime, mixed with muriate of magnesia; 7.6 sulphate of soda and sulphate of magnesia; 8.7 sulphate and carbonate of lime; = 194.0. Bergman gives a very different statement<sup>2</sup>: he experimented on water taken from a depth of sixty fathoms by Sparmann in the latitude of the Canary islands; his proportions are:—329.9 muriate of soda; 89.7 muriate of magnesia; 10.9 sulphate of lime; = 420.5. Higgins got from the sea water of our climate<sup>3</sup>:—167.3 muriate of soda; 106.6 muriate of magnesia; and 12.0 sulphate of lime;

<sup>1</sup> Mem. de l'Acad. des Sciences, 1772.—<sup>2</sup> Chemical and Physical Essays, i. 230.—<sup>3</sup> Black's Lectures on the Elements of Chemistry, 1803, ii. 714.

= 285.9. Vogel and Lagrange<sup>1</sup> obtained :—251.0 muriate of soda ; 35.0 muriate of magnesia ; 57.8 sulphate of magnesia ; 2.0 carbonate of lime and magnesia ; and 1.5 sulphate of lime ; = 347.3.

The analysis of Lavoisier, which was performed by evaporation and lixiviation with alcohol, is peculiar, from his finding muriate of lime and sulphate of soda, neither of which have been detected by subsequent chemists. Those of Bergman and Higgins, in not indicating the presence of sulphate of magnesia, which every other chemist has obtained, and is extracted on a large scale for economical uses ; the former chemist says expressly that he examined scrupulously for it but found none. The sulphate of lime is probably in all these cases, for the most part, a product of the analysis formed by the reaction of the sulphate of soda or magnesia, during the evaporation on a certain portion of muriate of lime, which is most likely one of the ingredients. The small portions of carbonates of magnesia and lime, can only be considered as accidental products of the decomposition of muriate of magnesia, and muriate or sulphate of lime. Murray, in an attempt to reconcile these discrepancies<sup>2</sup>, disclosed, by actual experiment, that the ingredients found, as well as their relative proportions, may be varied at pleasure, according to the mode of analysis which we choose to employ. By evaporation and the solvent action of alcohol of different temperatures and strengths, —the method employed by Lavoisier,—he obtained :—249.3 muriate of soda ; 35.5 muriate of magnesia ; 10.3 sulphate of soda ; 8.1 sulphate of magnesia ; 9.7 sulphate of lime ; = 312.9. The analysis by the common method of evaporation and crystallization gave :—251.9 muriate of soda ; 29.4 muriate of magnesia ; 17.5 sulphate of magnesia ; 2.7 sulphate of soda ; 9.9 sulphate of lime ; = 311.4. In both ways, it will be seen, that the common products are muriate of soda and muriate of magnesia, the large quantities of which render it probable that they are always the chief ingredients, although

<sup>1</sup> *Thomson's Annals*, iv. 200.—<sup>2</sup> *An Analysis of Sea Water*, in *Edin. Phil. Trans.* 1818, viii. 205.

their quantities may be affected by the reaction of the other salts. The chief difficulty occurs with the sulphate of magnesia and sulphate of soda, which seem to be entirely dependent on the method of analysis, in the one instance the alkaline, in the other the earthy, salt predominating; nor have we any means of establishing which of these two is the actual ingredient in the natural state.

Agreeably, therefore, to the principles illustrated at p. 75, the composition of sea water, taken from the Firth of Forth, may be stated as follows:—

1. Lime 4.0; magnesia 20.3; soda 131.8; sulphuric acid 19.7; muriatic acid 133.7; = 309.5.
2. Sulphate of lime; muriate of lime; sulphate of magnesia; muriate of magnesia; sulphate of soda; muriate of soda.
3. Muriate of soda 226.1; muriate of magnesia 34.4; muriate of lime 8.1; sulphate of soda 27.1; = 295.7.
4. Muriate of soda 251.9; muriate of magnesia 29.4; sulphate of magnesia 17.5; sulphate of soda 2.7; sulphate of lime 9.9; = 311.4.

Important differences exist in the quantity of solid matter obtained from the water of different seas; thus, the

Mediterranean Sea contains	410
English Channel,	380
German Ocean, at the Island of Föhr,	345
Ditto at Island of Norderney,	342
Ditto in Frith of Forth,	311
Baltic Sea at Apenrade in Sleswick,	216 <sup>1</sup>
Ditto at Kiel in Holstein,	200
Ditto at Doberan in Mecklenburg,	168
Ditto at Zobbot, near Dantzic,	76

The presence of the muriate of potash was demonstrated by Wollaston in sea water, before its discovery in mineral springs. Iodine has been found in the Mediterranean by Balard<sup>2</sup>, and in the Baltic by Pfaff. Bromine has been discovered by the same chemists in these

<sup>1</sup> *Pfaff*, das Kieler Seebad verglichen mit andern Seebadern an der Ostsee u. Nordsee, 1822, p. 25.—<sup>2</sup> *Annales de Chim. et de Phys.* xxviii. 178.



seas, and in the German Ocean; and Hermbstädt and Gmelin have also found it in the water of the Dead Sea <sup>1</sup>.

## 2. ATMOSPHERIC WATERS.

These form the last links in the great chain of aqueous fluid, which envelopes so large a portion of our globe, and is ramified in such innumerable streams throughout its inmost recesses. Subjected to a true process of natural distillation, they owe to this cause a degree of purity possessed by no other waters; and when collected in situations where they are not liable to contamination from foreign substances floating in the atmosphere, they almost equal that of artificially distilled water. At the same time there is less constancy in their phenomena, in consequence of the continual changes which are taking place in the free caloric and the electrical tension of the air, the two agents which exercise the most important influence on their origin.

Their specific gravity can hardly be said to differ from the standard of absolute purity, and any inequality that does exist, can only be detected by the most delicate experiments, when, of course, the causes of error operate with more force. Professor Zimmermann of Giessen, who has made many observations upon this point, states it to vary from 1000.1 to 1001.3 <sup>2</sup>.

Their foreign ingredients, when they do exist, are of two kinds, inorganic and organic. The inorganic substances are lime, magnesia, potash, iron, nickel, which has been as yet found in no terrestrial water, whether mineral or otherwise; muriatic, carbonic, sulphuric, and phosphoric acids. The organic substances are pyrrhine, and a matter somewhat analogous to gelatin <sup>3</sup>.

<sup>1</sup> *Poggendorff's Annalen*, viii. 475.—<sup>2</sup> *Kastner's Archiv*, i. 257.

<sup>3</sup> The organic matters deposited on the earth's surface by atmospheric waters, and which have of late years attracted so much of the attention of philosophers, very probably exercise a no mean influence in the general economy of nature. As they possess, in a very concentrated form, all the elements necessary for the nutrition of vegetables, they furnish an excellent pabulum for the first germs of life on the bare rock, the earliest state in the formation of a soil from which innumerable forms both of plants and animals are afterwards to derive an abundant supply of nutriment.

5. *Rain and Dew.*—Rain water has been very happily termed by Boerhaave the lixivium of the atmosphere. In fact, it is in the most favourable state for dissolving the different gaseous matters which are contained in the air, as well as the inorganic and organic particles which are rained along with the vapours which exhale from the earth's surface, in consequence of the minute state of division of this menstruum, and its numerous points of contact with the surrounding medium. The facility with which rain water becomes putrid, furnishes sufficient evidence of its intermixture with foreign ingredients, as pure water does not undergo this spontaneous change. In some cases, however, these impregnations are appreciable by chemical analysis; much, however, depends both on the season of the year, the climate, and the peculiar circumstances in which the water is collected. Lavoisier found it to contain no more than 0.397 of insoluble earths, and 1.31 of soluble salts. It is more than probable, however, from the discordance of chemists in the ingredients assigned to rain water, that they are more to be considered as owing to accidental circumstances than as constant products. Thus Kastner could discover no trace of iron in rain, but found in dew meteoric iron and nickel<sup>1</sup>. Zimmermann found in rain lime, oxide of iron, and muriate of potash. Brandes is said to have detected a great variety of ingredients<sup>2</sup>, viz. resin, pyrrhine, mucus, sulphate of magnesia, muriate of magnesia, carbonate of lime, muriate of soda (in largest quantity), sulphate of lime, carbonate of magnesia, muriate of potash, oxides of iron and manganese, and ammonia. Witting says that he has detected in rain, dew, and hail, carburetted hydrogen gas, but has not found it in snow.

Dew is much purer than rain water; but immediately on its deposition, it becomes impregnated with extractive and saline matters, which often form abundant efflorescences on the surface of the ground in those countries where the fall of dew is most considerable.

<sup>1</sup> *Kastner's Archiv.* v. 190.—<sup>2</sup> *Berzelius' Discourse*, 1829, p. 233.  
—<sup>3</sup> *Brandes' Archiv.* xi. 71.

6. *Ice and Snow*.—As the air in winter, and in elevated situations, from its low temperature, is less favourable to the exhalations which rise from the earth's surface, atmospheric water in its congealed state is purer than when fluid. For the same reasons, hail, which is chiefly formed during summer, is not so pure as the winter's snow. This description of water is generally quite free from the atmospheric and gaseous matters which frequently exist in rain. Marggraff found 100 quarts of snow carefully collected in Berlin, to yield traces of muriatic and nitric acids, besides 60 grains of lime, which he attributed to the vessels employed in the evaporation<sup>1</sup>; in the same quantity of rain water he found also some grains of the same acids, with 100 gr. of lime, derived from the same source. Traces of these acids have been also detected in the atmospheric water at Freyberg<sup>2</sup>. Link has found muriatic acid in the snow at Breslau. The idea has been hazarded, that the muriatic acid might derive its origin from the volatilization of a portion of the muriates contained in the sea water; and that the nitric acid might be formed by electrical processes and decompositions going on in the higher regions of the atmosphere.

It does not enter into the plan of the present work to give an account of the curious phenomena of red snow, red waters, red spots, &c. which have been observed on the Great St Bernard, in the arctic regions, and on New South Shetland; as these colouring matters are entirely owing to mechanical intermixture, whether we adopt with M. Ehrenberg, and the greater number of observers, the idea of their organic nature<sup>3</sup>, or with M. Chladni, that of their atmospheric origin, in consequence of chemical or electrical processes<sup>4</sup>.

<sup>1</sup> *Marggraff's Chymische Schriften*, 1762, i. 273.—<sup>2</sup> *Lampadius* in *Gilbert's Annalen d. Physik*, xxviii. 444.—<sup>3</sup> *New Observations on Blood-like Phenomena*, in *Edin. New Phil. Journ.* Jan. 1831, p. 122, and April 1831, p. 341.—<sup>4</sup> Chladni on *Fiery Meteors*, 1819; and in the *Annuaire du Bureau des Longitudes*, 1826.



## CHAPTER II.

## POSITION OF MINERAL AND THERMAL SPRINGS.

AN inquiry into the external relations of mineral and thermal waters is no less important than a knowledge of their internal qualities. If not of such immediate interest to the practical chemist and physician, an acquaintance with these relations is of primary consequence to the geologist, to the speculative philosopher, and to him who would arrive at a right estimate of their effects on the general economy of nature. But even to the chemist and the physician, these topics are by no means devoid of interest. The former can hardly advance a step towards an explanation of their origin, without an appeal to the different rocky strata which mineral waters traverse in their progress to the surface of the earth; and the Father of Medicine has long ago exemplified the necessity of resorting to the waters of a country for an explanation of the causes of many endemic diseases, and for the acquisition of one of our most important agents in combating these diseases. And if, as there is reason to believe, the observations of Hippocrates were meant to apply merely to the common drinking waters of a country, they may certainly be extended with far greater force to its mineral waters, those great therapeutical agents prepared by the bountiful hand of Nature herself. Indeed, without any appeal to the authority of names, it must at once be obvious to all, that a very imperfect view of the medical topography of any country would be given without examining, not merely the composition of a few of its more celebrated mineral springs individually, but also their number, their site, the cli-

mate of their environs, their similarity or dissimilarity with respect to one another.

It was long, however, before the position of mineral waters came to be appreciated according to its true value. This was in a great measure owing to the greater number of their analyses being executed on water transported to a distance from its source; nor, indeed, till the science of positive geognosy was reduced to something like fixed principles, was it possible to give an accurate account of all these relations, which can only be studied on the spot.

Under the History of the Position of Mineral Waters is comprehended a very extensive field of inquiry, into which the limits of the present essay forbid us to enter in all its details. Latitude, longitude, and altitude above the level of the sea, are the three conditions which assign the place of any spot on the earth's surface. It will, however, be most suitable to the present inquiry to consider mineral and thermal waters under their most important geographical, topographical, and geognostical relations, and to conclude with a brief account of the rocks which owe their origin to their forming influence, and of their general effects on the physiognomy of the earth's surface.

## SECTION I.

### GEOGRAPHY OF MINERAL SPRINGS.

ON taking a very general survey of the earth's surface as far as it has yet been explored by man, we are struck with the abundance of mineral and thermal waters which issue from its interior, ministering to the preservation of his health, perhaps even to the stability of the soil on which he treads, and producing important changes on the physiognomy of its surface.

## EUROPE AND ITS ISLANDS,

Commencing at the western extremity of the great high land which traverses Europe from west to east,—the peninsula comprising Spain and Portugal.

Portugal every where abounds in mineral waters, and is particularly remarkable for the number of those belonging to the thermal class. Indeed Alibert remarks: “Est peut-être le pays de l'Europe, qui, en regard à sa petite entendue, a le plus grand nombre d'eaux minerales, particulièrement de celles qu'on nommé thermales<sup>1</sup>.” Dr Tavares, in a work published in 1810, enumerates upwards of 200, of which thirty-seven are thermal; they are almost all sulphureous, and the few saline and ferruginous which do exist, have, in almost every case, a strong sulphureous smell. The following are a few of the more important:

## 1. THERMAL.

*Province of Mino.*

<i>Caldas das Taipas</i> in Guimarens, .	sulphureous.
<i>Caldellas de Rendusa</i> in Ucana, .	slightly chalyb. & sulphureous.
<i>Canaveres</i> in Guimarens, . . .	sulphureous.
<i>Gerez</i> in ditto, . . . . .	acidulous?
<i>Guimarens</i> in ditto, . . . . .	sulphureous.
<i>Monção</i> in Ucana, . . . . .	acidulous.

*Province of Tra Los Montes.*

<i>Caldas de Favaio</i> s in Villa Real, .	acidulous, sulphureous, and chalyb.
<i>Ponte de Cavez</i> in ditto, . . . . .	sulphureous.
<i>Rede de Corvaceira</i> in ditto, . . . .	ditto.
<i>Chaves</i> in Bragança, . . . . .	alcaline, acidulous.
<i>Pombal de Avicaes</i> in Torre de Montcorvo, . . . . .	sulphureous.

*Province of Beira.*

<i>Alcafache</i> in Visen, . . . . .	sulphureous.
<i>Aregos</i> in Lamego? . . . . .	weak sulphureous.
<i>Canas de Senhorim</i> in Visen, . . .	sulphureous saline.
<i>Carvalhal</i> in ditto, . . . . .	sulphureous.
<i>Santa Gemil</i> in ditto, . . . . .	ditto.
<i>San Pedro Dosal</i> in ditto, . . . . .	ditto.
<i>Prunto</i> in Coimbra, . . . . .	ditto.
<i>Ranhados</i> in Pinhel, . . . . .	ditto.
<i>Rapoila de Coa</i> in Castel Branco, .	sulphureous saline.
<i>Unhaes da Sarra</i> in Guardo, . . .	sulphureous.

<sup>1</sup> Alibert Precis, p. 590.



*Province of Estremadura.*

<i>Caldas da Rainhas</i> in Alemquer, .	sulphureous.
<i>Cascaës</i> in Torres Vedras, . . .	saline.
<i>Gaeiras</i> in Alemquer, . . . . .	sulphureous.
<i>Banhos do Duque</i> in Lisbon, . .	ditto.
<i>Miorga</i> in Alcobaca, . . . . .	saline.
<i>Torres Vedras</i> in Torres Vedras, .	chalybeate saline.

*Province of Alentejo.*

<i>Caheço de Vide</i> in Avir, . . . .	sulphureous.
--	--------------

*Kingdom of Algarves.*

<i>Monchique</i> in Lagos, . . . . .	sulphureous.
<i>Tavira</i> in Tavira, . . . . .	ditto.

## 2. COLD.

*Mino.*

<i>Braga</i> in Braga, . . . . .	sulphureous and chalybeate.
<i>Entre Rios</i> in Penafiel, . . . .	sulphureous.
<i>Padreiro</i> in Ucana, . . . . .	ditto.

*Tra los Montes.*

<i>Pedras Salgadas</i> in Villa Real, .	saline.
---	---------

*Beira.*

<i>Fonte Santa</i> in Pinhel, . . . .	sulphureous.
<i>Almafala</i> in ditto? . . . . .	saline.
<i>Alpreada</i> in Castel Branco, . . .	sulphureous.
<i>San Jorga</i> in Feira, . . . . .	ditto.

*Estremadura.*

<i>Alhandra</i> in Riba Tejo, . . . .	sulphureous saline.
---------------------------------------	---------------------

*Alentejo.*

<i>Alsustrel</i> in Ourique, . . . . .	saline.
<i>Avez</i> in Portalegre, . . . . .	sulphureous.
<i>Gaviao</i> in Crato, . . . . .	sulphureous chalybeate.
<i>Maria Viegas</i> in Portalegre, . .	sulphureous.
<i>Mertola</i> in Ourique, . . . . .	chalybeate.
<i>Onquella</i> in Elvas, . . . . .	acidulous saline.
<i>Portalegre</i> in Portalegre, . . . .	sulphureous.

The unfortunate political state of Spain since the reformation in the sciences of chemistry, has proved an insuperable obstacle in the way of our becoming acquainted with her mineral waters, although there is no doubt that they would amply repay an investigation, from the vast extent of the country, its highly interest-

ing geological structure<sup>1</sup>, and its proximity to Portugal, where they are so plentiful.

From the catalogue given by M. Laborde<sup>2</sup>, they seem to be most abundant in the provinces at the base and on the declivities of the great table land, occupying the whole central parts of the country from the Ebro on the north, to the Sierra Morena on the south; and from the frontiers of Portugal on the west, to the water-shed between the Mediterranean and the Atlantic on the east; and which is elevated from 2000 to 2500 feet above the level of the sea.

Thus, in the province of Catalonia, we have five cold mineral springs; those of *Monistrol* near Montserrat, *Val de Ebron* near Barcelona, *Tortosa*, *San Hilario*, and *Rivas*, the two last of these are acidulous: and ten thermal; those of *Caldas*, *Malavilla*, and *Tarill*, in the corregidorate of Talaru; *Garruga* and *Calditas* in that of Mataro; *Caldas de Mombrey*, *Gironne* and *Esparraguera*, near Montserrat; *Esplugas*, near to the Monastery of Poblet; and *Torello* near Barcelona: all of these are much frequented, but not one has been analyzed. In Valencia are three cold; *Navajas*, *Villa Vieja*, and *Sacatoba*, in Bunol: and two thermal; *Fuente Caliente*, south-west of Alicante, at the foot of a limestone hill, and another in *Buzot*, at the foot of the Sierra Gitana. In Murcia there are no cold ones of consequence, but five thermals; in a cavern near *Carthagena*, *Mula* near Murcia, *Anchena*, famous in the times of the Romans and the Arabs, *Fortuna*, and *Almaha*. In the great province of Andalusia, there are few mineral waters in the kingdoms of Seville, Cordova, and Jaen; but they are numerous in that of Grenada: the cold springs are in Seville, the sulphureous of *Chiclana* near Cadiz, *Colona* and *Cononada*; in Cordova, those of *Gonzalvillo* and *Cuerro*; in Jaen, those of *Liseda* and *Marmoles*; and in Grenada, those of *Piedra* near Antiquera, the acidulous of *Berchal* in the mountains of Alpuxarras, *Baranco de la Luna*, *Guardias Viejas* in Adra, a chalybeate in the white part

<sup>1</sup> See Professor Hausmann's Sketch of the Geology of Spain, in Edin. New Phil. Jour.—<sup>2</sup> View of Spain, 5 vols. 8vo. 1809.

of the *Sierra Vermejas*, *Brenabre*, and the sulphureous, acidulous, and saline waters of *Carratraca*<sup>1</sup>, north of Malaga, in all fourteen: there are no thermals in Cordova or Jaen; in Seville are the sulphureous of *Fuente de Sarna* near Ancos, and of *Medina Sidonia*; in Grenada, those of *Alhama de Seca*, a sulphureous in the red part of the *Sierra Vermeja*, *Hardales* near Malaga, *Alhama de Grenada*, near Almeria, in the district of Balerna in the Alpuxarras, *Alcolea* in the same mountains, at the foot of Mount *Javal Cohol*, very copious and hot; all of these are sulphureous, in all nine thermals. In the province of Galicia are two cold springs, *Camondes* and *Bejo*, both chalybeate; and nine thermal, *Caldas de Cuntis*, *Caldas de Reyes*, *Banda*, *Viana*, *Lugo*, *Orense*, celebrated in the time of the Romans under the name of the *Aquæ Celeniæ*, *Bertun*, *Contegada* and *Beran*. In Biscay, many of the cold waters are chalybeate; they are, *Alava*, *Villa Real*, *Urribari*, *Berritua*, *Thelleria*, *Merindad d'Arnatia*, and *Guipuzcoa*, seven in number: the thermals are all sulphureous; *Ceanuti*, *Urribari*, *Beritua*, *Armentia*, *Guipuzcoa*, *Ascoytia*, and *Atacea*; seven in number. In Navarre are the five hot springs of *Belascuain* near Pampeluna, *Arbe* near Roncevaux, *Fitero*, *Fiermes*, *Isaba*. In Arragon are several salt springs which yield by evaporation salt for the purposes of commerce, as those of *Fuente Garcia*, at Ancos and south of *Used*: the thermals are twelve in number; *Alhama de los Banos*, *Alquesar*, *Apies*, *Banos de N. S. de Ancos*, near *Bellel*, *Paracuellos de Xiloca*, near *Molina*, *Tiermas*, *Teruel*, *Juseo*, *Quinto*, *Benasque*, and *Baranco de Salto*.

In Old Castile are six cold springs; *Arvedo*, *Arabalde*, *Manganeses*, *Canajales*, *Boadilla de Rioneco*, and *Brieviesca*: and seven thermal; the acidulous ones of *Gravynos* and *Arvedillo*, and the sulphureous of *Bamba*, *Barco d'Avila*, *Lurganes*, *Navomonaes* and *Banos*. In New Castile, six cold; *Alameda Sagra*, *Colmenar Viejo*, *Vacio*,

<sup>1</sup> According to Alibert, 8 Castile pounds of the water contain of sulphate of magnesia 18 gr.; sulphate of lime 6 gr.; muriate of magnesia 2 gr.; alumina 7 gr.; silica 0.5 gr.; sulphuretted hydrogen 85.8 per cent.; carbonic acid 10.7 per cent.



*Cevica*, *Fuente del Canalon*, and *Anoner*, all of which are saline and cathartic : with the sulphureous thermals of *Fuente del Rosal*, *Buendia*, *Sacedon*, *Trillo*, *Fuente del Toro*, *Solur de Cabras*, and *Guadiala* ; seven in number. In La Mancha there is one hot spring, the *Fuen Caliente*, and seven cold. In Estremadura is one thermal, near the hermitage of *S. Bartolomeo*, east of Merida, where the remains of the baths frequented by the Romans are still to be seen ; and four cold chalybeates. In Leon are the cold sulphureous of *Amusco*, *Buron*, *Bavila*, *Fuente*, *Astudillo*, *Cano of St Jago de El Val* ; six in number : and four thermals ; the sulphureous of *Almeida*, *Ledesma*, *Bonar*, and *Barnos*.

It will thus be seen, from this rapid enumeration, that, as in Portugal, by far the greater number belong to the sulphureous class. But of all these sixty-two cold and seventy-eight thermal springs which I have named, scarcely any have been analyzed, although the greater number are much resorted to for their medicinal virtues.

The accurate geographer Cellarius places the *Aquæ Caldenses* of Pliny in the province of Tarragon, where are still to be seen some remains of the magnificence which the Romans displayed in the embellishment of their baths<sup>1</sup>.

France, a country on which Nature has lavished so many of her richest gifts, is equally distinguished for the number and variety of her mineral waters. Upwards of seventy-six are enumerated in the catalogue given by Alibert in 1825, which are employed for medicinal purposes, besides many others, of which no such use is made, either from their unfavourable localities, or from the vicinity of other springs of a more established reputation. About forty-five of these are thermal, and many of a very elevated temperature. Already we begin to perceive that grouping of mineral waters into linear series, or round some common centre, which will afterwards be seen to be one of the most curious phenomena connected with their history.

<sup>1</sup> Complete System of Geography, fol. 1747, i. 453.

A continuous chain of mineral waters issues from the northern declivity of the great Pyrenean range, or skirts its base from Bayonne at its Atlantic extremity to the plains of Rousillon, on the shores of the Mediterranean. More than thirty thermal springs are said to exist in this comparatively limited space<sup>1</sup>. We may enumerate among the more celebrated,—*Dax*, in the Department des Landes, *Tercy*, *Prechac*, *Cambo*, not far from Bayonne, *Eaux Bonnes*, in the valley of Ossan, *Cauterets* in the valley of the same name, *St Sauveur* in the valley of Lavedan, *Bareges*, *Bagneres*, *de Bigorre*, *Cap Bern*; *Bagneres de Luchon*, *Encausse*; *Audinac*, *Ussat*, *Ax* in the little district of Foix; *Vernet*, *Barbotan*, *La Preste*, *Molix*, *Vinca*, *Arles*, and *Oletta* in Roussillon. A striking uniformity of composition is evident in most of these springs. They have been generally referred to the sulphureous class, in consequence of being largely impregnated with sulphuretted hydrogen. Can any analogy be considered to exist, in this respect, between them and the sulphureous springs we have just seen to be equally characteristic of the mineral waters which emerge from the southern declivity of the great peninsular tableland<sup>2</sup>? Their predominant solid matters are the salts of soda, especially the sulphate and carbonate. The muriate predominates in those of *Dax*, *Cauterets*, and *St Sauveur*. Silica is a prominent ingredient in the springs of *Bareges*, *Cauterets*, *St Sauveur*, *Bagneres de Luchon*, *Eaux Bonnes*<sup>3</sup>, which is no doubt intimately connected with the recent discovery of *Longchamps*, of a considerable proportion of caustic soda in the two first of these waters; we might be inclined rather to consider it as existing in the state of carbonate, were it not distinctly stated by so distinguished a hydro-analyst to be in the caustic state. Magnesian salts are stated to have been

<sup>1</sup> *Osann's Darstellung*, i. 160.

<sup>2</sup> This analogy would be strengthened were it ascertained by actual measurement that the valley of the Ebro in Arragon and Navarre was elevated to a considerable height above the level of the sea.

<sup>3</sup> *Lüdemann's Travels in the Pyrenees in 1822*, pp. 335, 338, 341, 343.

found in those of Cambo, Eaux Bonnes, Bareges, and Bagnères de Bigorre<sup>1</sup>.

Very few mineral waters exist in the plains of the Garonne extended at the foot of the Pyrenees: thus we have the thermal sulphureous springs of *Castera Verduzan*, in the Department of Gers, close to which rises a cold chalybeate spring.

Continued from the eastern extremity of the Pyrenees is a series of springs, extending north-east into the Vivarais and the provinces of central France, which, though not disposed in the same regular series as those of the former chain, may perhaps be considered as parts of one system. The first of note met with in proceeding north from Roussillon are the thermal waters of *Rennes les Bains*, in the Department de l'Aude, the predominant constituent of which is oxide of iron, associated with calcareous and magnesian carbonates; silica is here also present. In the Department de l'Herault, we find the thermals of *Avene* and *Balaruc*, in both of which the muriates of soda and magnesia are the chief ingredients, and those of *Malou* and *Capus*, in which carbonate of soda predominates; next is the sulphated chalybeate of *Alais*, in the Department du Gard. Parallel with these to the north, in the Department de l'Aveyron, are the thermal waters of *Sylvanes*, predominant constituent muriate of soda; of *Cransac*, predominant constituent sulphate of magnesia; the acidulous spring of *Andabra*; the thermal sulphureous of *Bagnols*, in Department of Lozere; in the Department of Ardèche, the alkaline thermals of *St Laurent les Bains*; and the cold alkaline spring of *Vals*, remarkable for its very large quantity of the carbonate of soda.

These latter springs, which already begin to resemble them in their mineral constituents, conduct us to the group which characterizes the district of Auvergne in central France, including the departments of Cantal, Puy de Dome, and Allier;—a group not less remarkable than the Pyrenean for the number and the uniformity of com-

<sup>1</sup> Alibert, *ad locum*.



position of its individual waters. We here find the thermal waters of *Chaudes Aigues* ; *Mont d'Or* ; *St Nectaire*, *Clermont-Ferrand*, *Chateau Neuf*, *Chatel Guyon*, *St Mart*, *St Allyre* ; *Vichy*, *Bourbon l'Archambault*, and *Neris* :—the cold springs of *St Marie*, *St Martin de Valmeroux* ; *Bar*, *St Myon*, *Medague*, *Vic le Comte*, *Langeac* ; *Chateldon*, and many others. In all these warm springs carbonate of soda is the predominant constituent, often associated with a large dose of the muriate, which, in those of *St Nectaire*, even slightly exceeds the carbonate in quantity. Many of them are traversed by copious streams of carbonic acid, but little of which, however, can in most cases be held in solution, in consequence of their high temperature ; at *St Nectaire* and *Chaudes Aigues* the carbonic acid is accompanied with sulphuretted hydrogen. The waters of *Neris* contain azote. No obstacle being presented in the cold springs to the free solution of the carbonic acid, which is discharged in such profusion from the soil of this district, they are almost all of the acidulous class, and contain carbonate of soda as their chief solid ingredient. On the outskirts of *Auvergne* the same general character prevails, thermal waters are less abundant, carbonic acid and carbonate of soda continue the principal ingredients : as examples, need only be cited the springs of *Mont Brison* and *St Galmier*, in the Department du Loire ; of *Pougues*, near *Nevers*, which contains in addition silica and the oxide of iron ; of *St Alban*, near *Lyon*, on the left bank of the Loire (66° F.), which also contains the oxide of iron, together with some alumina. The thermal springs of *St Honore* in the mountains of *Morvan*, thirteen leagues from *Nevers*, present a composition somewhat peculiar : according to the analysis of *Vauquelin*, they contain, besides oxide of iron as their characteristic constituent, subcarbonate of potash, silica, a trace of sulphur, with some vegeto-animal matter. There issue from the western side of the plateau the sulphureous thermals of *Evaux*, in the Department of *Creuse*, which also contain some carbonic acid (5 cub. in. per pint), and their predominant constituents are the sul-

phate and carbonate of soda ; and the cold sulphureous springs of *Roche Posay* in the Department du Vienne, referred by Alibert to the chalybeate class.

Comparatively few mineral waters issue forth from the basins of the lower Loire and Seine, or from the vast plains which extend westwards to the Atlantic Ocean ; hardly any of them are thermal, and their composition is of quite a different character, the salts of iron usually predominating, with or without proportions of carbonic acid, sulphuric acid, sulphuretted hydrogen, and sulphate of alumina. In the Department du Loiret is the carbonated chalybeate of *Noyers*, and the sulphated chalybeates of *Ferriers* and *Segray*, which contain a proportion of sulphate of magnesia. In the Department du Marne is the sulphated chalybeate of *Sermaise* ; and, proceeding westwards, the carbonated chalybeate of *Provins*, in which Vauquelin detected manganese and silica ; of *Chapelle Godefroy*, in Department de l'Aube ; the celebrated sulphureous chalybeate of *Enghien*, at Montmorency, near Paris ; and, lastly, the carbonated chalybeates of *Passy* under the walls of the metropolis, of *Rouen*, of *Forges*, of *Aumale*. Isolated from all others, are the thermal sulphureous springs of *St Amand* (79° F.) in the Department du Nord ; of *Bilazai*, in Department des deux Sevres (77° F.) ; and the cold carbonated chalybeate of *Fontenelle*, in the Department of Vendee. From this enumeration it will be seen that most of the springs can be considered as belonging to no common system ; and, accordingly, their predominant constituents are such as are observed to be least constant, and most liable to be influenced by external atmospheric changes.

Returning to the eastern extremity of the Pyrenees, and crossing the Rhone towards the western base of the Alps of Dauphiny, we again meet with a series of springs ranging northwards, of a peculiar composition. In the Department of the Mouths of Rhone are the thermals of *Aix*, which are remarkable for their purity, containing a trifling quantity of earthy salts. In the Department of the Low Alps are the sulphureous thermals of *Greoulx* and *Digne*, the former of which contains, in

addition to its characteristic gas, a considerable proportion of carbonic acid (8 cub. in. per pint) and muriate of soda. Carbonic acid and muriate of soda continue to predominate in the thermal springs of *La Motte*, in the Department of the Isere, and the cold ones of *Uriage*, near Grenoble: in the latter, however, as these ingredients are associated with a large quantity of sulphuretted hydrogen and some oxide of iron, it is generally referred to the sulphureous or chalybeate classes. But no one can mistake the analogy which the two other substances establish between them and those of *La Motte*, and of almost all the hot and cold springs in the provinces which bound the great high land of Switzerland on the west and north-west. Thus the muriate of soda is the chief ingredient, and generally in large quantity, in the thermals of *Bourbon-Lancy*, Department of Saône and Loire; of *Luxueil*, Department of Upper Saône; of *Bourbonne les Bains*, Department of Upper Marne; of *Plombières* and *Bains*, Department of the Vosges: to which may be added the well known salt springs of *Salins*, south of Besançon, which have yielded from the earliest periods such enormous quantities of salt for economical purposes; and those of *Jouhe*, in the Department of the Jura, which resemble in many points the celebrated waters of Seidlitz and Saldschütz, in Bohemia. These latter, and those of *Pouillon*, in the Department of the Landes, and *Campagne*, Department de l'Aude (82° F.), are the only springs in France which are at all remarkable for a very large quantity of magnesian salts.

Such is a rapid sketch of the distribution of the principal mineral and thermal waters of this vast empire, which is equally distinguished for their number, the variety of their composition, and their elevated temperature. Viewed in all their generality, were we disposed to group them under a geographical arrangement,—or, if the reader prefers that denomination, a geographical classification,—they might perhaps be considered as forming four grand divisions. The first would comprehend the Pyrenean series, of which the predominant con-



stituents are sulphuretted hydrogen and sulphate of soda; the type of this order is Ax. The second would comprehend the series of Auvergne, of which the principal constituents are carbonic acid and carbonate of soda; the type of this order would be Vichy or Vals. The third group would be that of the Western Alps and Jura, its principal constituent is the muriate of soda; the type of the order Luxueil. The fourth and last would include the numerous chalybeates scattered over the provinces on the banks of the Loire and Seine; the type of this order Enghien. Leaving, however, these speculative ideas, let us proceed to an examination of the mineral waters in the

Alps and adjacent territories.—They are tolerably abundant in the western portion of the chain in Savoy and Switzerland, but are comparatively rare in its eastern and larger half, including the Tyrol, Styria, and upper part of Austria. Compared with the springs of other countries, they contain but a small proportion of solid matters, chiefly of the earthy carbonates and sulphates. In but few do we find the predominant constituent to be the carbonate of soda constituting alkaline waters, and the muriate of the same base is only found in two small groups; but there its characters are well marked. Sulphuretted hydrogen is certainly by far the most common ingredient, sulphureous waters being almost the half of the total number. The hottest of the thermal waters, those of Leuk, do not exceed the temperature of 124° F. Most of them have been discovered since the time of Saussure<sup>1</sup>, the venerable historian of the Alps; and it is probable that many more yet remain unknown.

A group of hot springs surrounds the flanks of the colossal Mont Blanc in Savoy; the principal of which are *Courmayeur* and *St Didier* on its southern precipice, the chief constituents of which are the sulphates of lime and magnesia, with a little carbonic acid in the former; those of *Echaillon* and *St Gervais*, in which the sulphate of soda predominates; those of *St Pucelle*, *Brida*, and

<sup>1</sup> *Bakewell*, in *Philosophical Magazine*, Jan. 1828, p. 14.

*Moutiers* in the Tarentaise ; of *Aix les Bains* in Savoy ; and of *Chamouni*. In the valley of the Rhone, we find in succession the three sulphureous springs of *St Maurice*, *Leuk*, and *Naters*. Near the entrance of this river into the Lake of Geneva is the cold chalybeate of *Trois torrens*.

Crossing over the St Gothard to the sources of the Rhine, we find ranged along the ridge of the Grisons the acidulous springs of *Belvedere*, *Bernardino*, *St Moritz*, and *Schultz*, in which calcareous salts predominate, and of *Fideris*, which is a little to the north of the above line, and differs from these springs in containing carbonate of soda as its chief ingredient. This last perhaps may be considered as the transition to the thermals of *Pfeffers*, *Peiden*, and *Vals* in the valley of the Rhine, in which we find sulphate of soda predominant. And, lastly, to complete the series of springs of this group are the sulphureous waters of *Wichler*, *Jenatz*, *Alvenen*, and also of *Peiden*, just mentioned. The alkaline waters of *Tarasp*, also in the Grisons, are of quite a distinct character ; they are remarkable for the very large quantity of solid matters generally (see p. 53), and more especially of carbonate of soda (see p. 17), being only susceptible of comparison in this respect with the springs of *Vals*, *Bilin*, and *Fachingen* ; they also contain much muriate of soda and iron.

Descending the Rhine towards the Lake of Constance, on its left side, in the Cantons of St Gallen and Appenzell, are the cold sulphureous waters of *Gonten* and *Bleicherbad* ; the chalybeates of *Schmerikon* and *Wahlstadt* ; and the carbonated springs of *Gyrenbad* and *Dorfbad*. In all of these, earthy salts are the predominant constituents in point of quantity. Several springs emerge from the foot of the mountains of Jura and of the Bernese Oberland. The only ones which can be called thermal, are the sulphureous spring of *Iferten* (75° F.) in the Pays de Vaud, in which the chief solid constituents are the sulphates of lime and magnesia, with a little muriate of soda and iron ; and of *Weissenburg* in the Canton of Bern (84° F.), in which the sulphates of lime

and soda predominate. Besides these, we have in the same district the cold sulphureous waters of *Bex*, *Lalliazbad* (in which Struve has found azote), *Gurnigel*, *Leisingen*, *Aarzihl*, *Thalgut*, and *Wickartswyl*. The Canton of Bern is principally remarkable as containing the greater number of the chalybeates of Switzerland; the principal of these are *Blumenstein*, *Engistein*, *Lochbachbad*, and *Worben*, to which we may add those of *Rolle* and *Lausanne* in the Pays de Vaud. The only alkaline spring is that of *Rosenlawibad*, which may be compared with that of Tarasp in the Grisons, for its large proportion of the carbonate of soda.

Farther down the Valley of Aar, however, alkaline springs increase in number: we find, for instance, in the Canton of Lucern those of *Bad*, *Schwarzenberg*, *Kirchlerau*, and *Niederwyl*. Near its entrance into the Valley of the Rhine are the well-known sulphureous thermals of *Schinznach* and *Baden*, which contain, beside sulphuretted hydrogen, a considerable quantity of sulphate of soda. *Attis-holz* is the only spring in which the sulphate of soda alone is the predominant constituent. Lastly, in the Valley of the Limmat is the simple cold sulphureous water of *Nydelbad*.

Returning to the Grisons, and tracing eastwards the ridge of the High Alps, not a single mineral water is met with till we arrive at the hot alkaline springs of *Gastein* in the district of Salzburg, which are in fact the only mineral springs with which we are acquainted in the whole of the mountainous district of the Tyrol, forming a remarkable contrast to the Swiss Alps.

Another hiatus of prodigious extent exists before we arrive at the mountains which bound the basin of Vienna, in which we find the thermal sulphureous waters of *Baden*, and the cold sulphureous springs of *Untermeidling* and *Pyrarwarth*.

Before proceeding farther eastwards, let us return to the western extremity of the chain, and examine the distribution of the salt springs which may be considered as connected with the system of the Alps. We have already seen that they skirt the western base of the chain



in Dauphiny and the Vosges. They continue in the same way to form distinct groups along its northern base on the southern limits of the Black Forest, and the basin of Bavaria. Two distinct systems can be here recognised: a western in the Black Forest and the valley of the Rhine, which perhaps more properly belongs to the system of the Black Forest, to be afterwards considered. The chief members of this group are the saline and brine springs of *Badenweiler* and *Sachingen* in Baden, and of *Ueberlingen* in Würtemberg. An eastern in the district of Salzburg, of which the principal are the brine springs of *Rosenheim*, *Reichenhall*, and *Ischl*. At *Rosenheim* and *Gecking*, in this last district, are found also cold sulphureous waters.

At the southern base of the Alps in Piedmont, besides those already noticed at the foot of Mont Blanc, we find a considerable number of sulphureous waters, many of which are thermal. The principal are the hot springs of *Valdieri* and *Vinadio*, in which muriate of soda is the chief solid ingredient; of *Acqua Santa* and *Penna*; of *Roccabigliera*, in which Foderé has detected muriate of potash and silica. These are associated with a great number of cold sulphureous springs, such as *Lu*, *La Saxe*, *Castel Nuovo d'Asti*, *Montasia*, *Calliano*, *Vignale*, *Castiglione*, *Lampiano*, *Genesio*, *Sta. Fede*, *Bobbio*, *Cammarà*, *La Caille*, *Voltaggio*, *Retorbido*, and many others. And with a few chalybeates, as those of *Bricherasio*, *Ceresole*, *Morbello*, *Bibiana*, *Molla*, &c. The thermal of *Craveggia* has for its predominant constituent the sulphate of alumina.

Farther to the east, near Bormio, on the banks of the Adda, are the thermal waters of *Worms* and *Masino*, which resemble very much those of Pfeffers, immediately to the north, on the opposite side of the central chain; their predominant constituent being the sulphate of soda.

From this review of the distribution of the mineral waters of the Alps, it will be seen that here, no less than in France, we can observe that collection into certain groups,—that accumulation, as it were, round certain centres for which that country is so remarkable. Here.

however, these groups are not characterized by that strict uniformity of composition observable in the other country, sulphureous, purging, and alkaline waters, all entering into the composition of most of the groups. A certain link of connexion,—a passage, if this somewhat theoretical expression is admissible, can be traced even between these apparently isolated members. For instance, in the group of the Grisons, we have, first, the true sulphureous waters of Alvenen and Jenatz; the sulphureous and purging of Peiden; the pure purging of Vals and Pfeffers; and, lastly, the alkaline of Gyrenbad. The chalybeate waters are almost entirely ranged round the Bernese Oberland and the Valley of the Aar. The acidulous waters are limited to a narrow space near the very crest of the chain in the Grisons. And, with the exception of those of Schinznach and Baden, the thermal springs are confined to the central ridge, or its immediate base.

Not a single thermal water exists in the mountains of the Black Forest, and the adjacent countries of Baden and Würtemberg, except that of *Baden* in Baden, the principal ingredients of which are muriate of soda, with a little of the carbonate; and of *Wildbad*, remarkable for its purity, its whole solid contents not much exceeding one part in 10,000 of water, chiefly carbonate of soda, associated with azote and a little carbonic acid. Many acidulous springs, however, and acidulated chalybeates, supply their place. The principal are the chalybeates of *Riepoldsau*, *Griesbach*, *Petersthal*, *Antogast*, and *Baden* in the duchy of the same name, all of which contain a large excess of carbonic acid; of *Imnau* and *Niedernau* in the kingdom of Würtemberg, on the opposite side of the chain, which are of exactly the same character. The purely acidulous waters are those of *Göppingen*, *Deinach*, and *Langensteinbach*, which contain, besides carbonic acid, merely a trifling quantity of earthy carbonates. A series of cold sulphureous springs stretches northwards along the Würtemberg side of the chain: we there find in succession those of *Sebastianweiler*, *Bahlingen*, *Reutlingen*, *Boll*, *Zaisenhausen*, *Langenbrucken*, and

*Wiesloch*. Not far from the hot spring of Wildbad is the cold alkaline water of *Zellerbad*, and the cold saline waters of *Kannstadt* and *Hall*.

Only a few cold springs are met with in the plains of Bavaria. In the basin of the Danube are the sulphureous waters of *Wemding* and *Kreuth*, in the district of Pappenheim; of *Abensberg* and *Abach*, near Ratisbon; and the chalybeates of *Krumbach* and *Eschaloh*. In the basin of the Main are the sulphureous waters of *Neumarkt*, near Nürnberg; of *Wipfeld*, near Würzburg. On approaching the mountains of Franconia, which bound Bavaria on the north, as the Black Forest on the west, we again meet with carbonic acid. Thus the sulphureous spring of *Bocklet* contains, along with its characteristic gas, a large proportion of carbonic acid; and, at *Kissingen*, the acid is associated with the muriate of soda, besides a distinct brine spring.

The springs which we have just seen to form a nearly continuous series in the provinces situate on the right bank of the Rhine, serve as a sort of transverse bond of connection between the groups we have been considering in the south of Europe, and another parallel traversing the centre of Germany from east to west, which is fully as remarkable as any of the preceding, from the uniformity of composition which characterises its component members. The connecting links between them are the chalybeate of *Auerbach*, a few miles to the north of Mannheim, on the right bank of the Rhine, and the sulphureous water of *Nierstein*, a little to the south of Mainz, on the opposite bank of that river.

Let us, however, commence at its western extremity. Here we find a series of springs, situated in or grouped at various distances round the Eifel mountains, in the Prussian provinces on the left bank of the Rhine. The hot-springs of *Bertrich* are the first thermal waters we meet with in proceeding northwards: their predominant constituent is the sulphate of soda, with a little of the muriate, and some carbonated earths. On its northern side are the hot sulphureous waters of *Aachen*, which contain, besides sulphuretted hydrogen, azote, and car-



bonic acid, as solid constituents, the carbonate and muriate of soda; and the hot-waters of *Burtscheid*, not far from the preceding, which are the hottest of the thermal springs of Germany (172° F.). There are two springs at *Burtscheid*, a sulphureous and a saline, the latter of which is the hottest: the sulphureous spring nearly resembles those of Aachen in its composition; in the saline spring, the ingredients which are next to the muriate of soda in point of quantity, are the carbonate and sulphate of the same base. Besides these thermal waters, there emerge from this district an immense number of cold springs, almost all of which are largely impregnated with carbonic acid, either pure, or associated with the carbonate of soda, and a little iron. I need only mention the numerous springs in the *Dreiser-Weiher*<sup>1</sup>, all of which contain much carbonic acid, carbonate of soda, and a little iron: the springs of *Birresborn*, the ingredients of which are the same, with the addition of muriate of soda; of *Gerolstein*, the composition of which is nearly the same; a spring in a mine south of *Bertrich*, on the right bank of the Moselle (82° F.), with nearly the same ingredients as *Bertrich*, only in smaller quantity: the nearly pure acidulous springs of *Obermennig*, *Godesberg*, *Tonniststein*, *Heilbronn*, and *Hep-pingen*, near Bonn; the alkaline acidulous at *Brohl*; the saline acidulous of *Roisdorf*, predominant constituents muriate, carbonate, and sulphate of soda. On the western side of the Eifel, the well known acidulous chalybeates of *Spa* and *Malmedy*. Crossing over to the opposite bank of the Rhine, we arrive at the duchy of Nassau, comprising the Westerwald and Taunus districts. This little space can only be compared with Portugal in the number of its mineral waters. Upwards of 124 springs are enumerated by *Stift*<sup>2</sup> in a space about 70 miles long by 50 broad. Of these four are thermal.

<sup>1</sup> Or lake of mineral waters. *Bischof* (*Vulk. Mineral quell.* p. 162.), mentions, that all the mineral waters of this district are called by the natives *Dreis*. This *Weiher* is one of the numerous craters of the Eifel Mountains, which, from the abundance of its carbonated springs, has obtained the name of *Dreiser-Weiher*.

<sup>2</sup> *Geognost. Beschreib. des Herzogthum Nassau*, 1831, p. 532.

Soden, Schlangenbad, and Wiesbaden, on the southern declivity of the Taunus, and Ems on its northern, in the valley of the Lahn. In *Soden*, the predominant ingredients are carbonic acid and muriate of soda: in *Schlangenbad*, which contains but a small quantity of solid matters, the principal are carbonic acid and carbonate of soda: in *Wiesbaden*, carbonic acid and muriate of soda: in *Ems*, carbonic acid and carbonate of soda. The principal cold springs are the saline and brine springs of *Cronberg*, *Wiesbaden*, and *Eltvile*: the carbonated chalybeates of *Ramschied*, *Langenschwalbach*, *Schiestheim*, *Burgerschwalbach*, *Dinkhold*, and of *Lamschied*, on the opposite banks of the Rhine: the well-known saline acidulous springs of *Selters*: the alkaline acidulous of *Fachingen* and *Geilnau*; and the nearly pure acidulous water of *Montabaur*, which, as it is separated some distance to the north of the others, is characterized by a marked peculiarity of composition. Not a single sulphureous spring is found in this immense group, or rather assemblage of groups<sup>1</sup>, of acidulous waters. It is only at the very southern extremity of the duchy that we find the sulphureous waters of *Nied*, *Höchst* and *Weilbach*, and, on the opposite side of the Rhine, that of *Nierstein*, formerly referred to. The brine springs of *Kreuznach*, on the same side of the river, may perhaps be considered as the south-western prolongation of those of *Soden* and *Wiesbaden*, being situate in the valley of the Nahe, which nearly corresponds with the opposite one of the Main, as those of *Nauheim* and *Salzhausen* in Hesse Darmstadt are their north-eastern.

The mountain ranges which are continued north and north-east from the Westerwald, through the Teutoburg and Habichtswald, to the mountains of the Hartz, conduct us to another numerous group of very celebrated mineral waters. Not a single thermal water is found, however, in the whole of this tract. Cold sulphureous

<sup>1</sup> M. Stiff considers that they are referable to five distinct series, parallel to one another, with a direction NE. and SW. corresponding to that of the Westerwald and Taunus, the valleys of the Lahn, of the Main, and of the Nieder.

and chalybeate springs form by far the greatest proportion, with an occasional alkaline or acidulous spring. Here, also, the saline springs form a distinct range along the banks of the Lippe, on the northern declivity of the Haarstrang mountains in Westphalia. In the Habichtswald district are the carbonated chalybeates of *Wildungen*, *Kleinesm* and *Dorfsgeismar*, which contain, in addition to their characteristic ingredients, a few of the earthy carbonates, and, in the former, a trifling quantity of the carbonate of soda; and of *Hofgeismar*, with sulphate of soda. Farther north, near the Tentoburgwald are the sulphureous springs of *Fiestel*, *Nammen*, *Valdorf* and *Brackel*, in Westphalia; of *Meinberg*, with the sulphate of soda; of *Winslar* and *Eilsen*, with the sulphate of lime; of *Northeim* and *Limmer*, in Hanover. The highly carbonated chalybeates of *Pyrmont*, *Driburg*, *Meinberg* and *Rehburg*. The brine springs are in succession from west to east; those of *Unna*, *Königsborn*, *Werl*, *Soest*, *Westerkotten*, *Salzkotten*, and *Godelheim*, along the line of the Lippe, and farther north of *Salzuffeln* and *Pyrmont*.

Another range may be considered as stretching eastward from the Taunus through the Vogelgebirge, Rhöngebirge, Forest of Thuringia, and Fichtelgebirge, into the mountains of Bohemia. Neither does this present any thermal springs. Its cold springs are so far analogous to the preceding, that many carbonated chalybeates are met with, but they are strikingly contrasted by the deficiency of sulphuretted hydrogen, so abundant in the former group. The first in this series is the acidulous spring of *Schwalheim* in the Wetterau, with the muriate of soda, and a composition very analogous, except in the smaller quantity of the ingredients to that of Soden, which it immediately succeeds on the north-east. We then come upon the acidulated springs in the mountains of Franconia, of which we have formerly (p. 133.) seen examples in those of Bocklet and Kissingen. Of these the principal are the chalybeates of *Bruckenuau*, which contains also the carbonate of soda: of *Langenuau* and *Liebenstein*: of *Sinnberg* with the carbonate, and *Wer-*



nartz with the muriate and sulphate of soda. Of *Johannisberg*, *Weyhers* and *Koden*, near Fulda. And, lastly, the nearly pure acidulous waters of *Kondrau*, *Gosel*, and *Fixen*. To the north of these mountains, there ranges a series of brine-springs, all situated in the line of prolongation north-east of those of Manheim and Salzhausen, and which, perhaps, are referable to the same system, although they are often separated by considerable intervals. First in order comes *Salzungen*, on the banks of the Werra; then *Sondershausen*, not far from which are those of *Frankenhausen* and *Halle*. More than eighteen mineral waters have been discovered in the Fichtelgebirge<sup>1</sup>, but very few of them have been exactly analyzed. The principal are the carbonated chalybeates of *Steben*, *Alexandersbad* and *Condra*.

These conduct us to the important group which characterizes the centre of Germany, encompassing the range of the Erzgebirge in the north of Bohemia and Saxony. In respect both of composition and position, they may be considered as constituting three distinct groups; the purging, the alkaline, and the bitter waters. The first of these seems to be accumulated in the north-west angle of Bohemia, at the junction of the Erzgebirge and Böhmerwaldgebirge. The type of this order are the celebrated hot-springs of *Karlsbad*, the Geyser of Germany, the predominant solid constituents of which are the sulphate, carbonate, and muriate of soda; to which may be added the cold springs of *Franzensbad*, in which the principal ingredients are the sulphate, carbonate, and muriate of soda; of *Marienbad*, with the sulphate and muriate of the same base; and of *Königswart*, which contain but a small proportion of solid matters, and are remarkable for the predominance of insoluble earthy salts, such as the carbonates of lime, magnesia, and silica; the principal soluble salt is the carbonate of soda. The second group is principally collected at the eastern extremity of the Erzgebirge, on the northern declivity, and at the foot of the Bohemian Mittelgebirge.

<sup>1</sup> Bischof, u. s. p. 189.

The type of this order are the equally famous thermal waters of *Teplitz*, which are but weakly impregnated, chiefly with the carbonate of soda; to which may be added the alkaline thermals of *Wolkenstein* and *Annaderg* (70° F.), and the well-known cold alkaline springs of *Bilin*, remarkable for their large quantity of the carbonate of soda. The third group is confined to a limited space in the valley of the Eger, equidistant from the springs of Karlsbad and Teplitz: its principal members are the springs of *Saidschütz* and *Seidlitz*, in both of which the predominant constituent is the sulphate of magnesia, and those of *Püllna*, which also hold in solution a considerable proportion of the same salt, but where the sulphate of soda predominates. We can hardly consider as forming a fourth group the different chalybeates scattered over the district, such as those of *Brambach*, *Schönberg*, *Elster*, *Tharandt*, *Schandau*, &c. Carbonic acid is discharged in great quantities from almost all the alkaline, purging, and chalybeate waters of Bohemia, often with great impetuosity, as in the Sprudel, and Karlsbad acidulous spring, and in the latter is accompanied with the singular phenomenon of a third of all the solid ingredients being silica. The same acid continues to be discharged in great quantities from most of the springs in Silesia and Glatz, on the northern declivity of the Riesengebirge. Many of them have been classed among chalybeate waters, from their medicinal effects, although the carbonate of soda is the predominant constituent. Such are the springs of *Liebwertha*, *Altwasser*, *Flinsberg*, and *Salzbrunn*, in Silesia; of *Cudowa*, *Reinerz*, and *Niederlangenau*, in the county of Glatz. The springs of *Charlottenbrunn* and *Freudenthal* in Silesia contain, in addition to the carbonic acid and carbonate of iron, only a few earthy salts. The springs of *Buckowina* are well known for their large quantity of the sulphates of alumina and iron. There are two thermal waters in the district of the Riesengebirge; the sulphureous ones of *Warmbrunn* in Silesia, which contain, besides sulphuretted hydrogen, only a small quantity of the sulphate and carbonate of soda; and of *Landeck* in

Glatz, which contain, besides their characteristic gas, a little carbonic acid and the sulphates of lime and soda, but none of the carbonate.

Such is a rapid outline of the most important mineral and thermal waters of the centre of Germany. Although they are not extended over so large a space as the more southerly range, they are much more uninterruptedly continuous. Compared, however, with the latter, there is a remarkable deficiency of hot-springs. Carbonic acid is, for the most part, the characteristic gas, as sulphuretted hydrogen is of the other.

Let us here pause for a moment, and inquire whether our examination has led as yet to any general principles. Can it be laid down as a law, that thermal waters will not be found in extensive plains, remote from mountain ridges? Observation would seem rather to answer this question in the affirmative, as far as Europe is concerned. In the basin extending from the northern base of the Alps to the mountains of Bohemia and Franconia, and from the Riesengebirge on the east, to the Black Forest on the west, no thermal waters whatever exist, and very few mineral springs of any description. We are also as yet without any records of their presence in the vast plains included between the Black Sea, the Baltic, and the north-east of Saxony, the rains of which feed the sources of many of the mightiest rivers of Europe. But this is somewhat anticipating the subject. Before, however, glancing at the mineral waters of the north of Germany, let us examine the prolongation eastward of the southern range, through the mountains of Hungary.

Hungary is a country new for observation. As it is only very recently that we have become at all acquainted with its physical constitution, a corresponding deficiency exists in our knowledge of the mineral waters of this vast country. In fact, there scarcely exists an analysis of any one of its numerous waters, and we are compelled to rest satisfied with a few scattered notices of their existence and predominant ingredients, although many have acquired great reputation as medicinal agents. Beudant mentions, that upwards of 400 have been enu-



merated by authors, and that scarcely a single county is without several<sup>1</sup>. Some are thermal, some cold. The majority are acidulous and calcareous, some are acidulo-chalybeate, and acidulo-sulphureous. The more celebrated are the hot acidulo-calcareous waters of *Eisenbach* and *Glashütte*, near Schemnitz; of *Erlan*, near the mountains of Matra; the acidulo-sulphureous of *Buda*, on the banks of the Danube; the cold acidulous waters of *Trentsen*, *Barthfeld*, *Ticzolcz*, *Hradek*, and *Lublo*, at the foot of the central ridge of the Carpathians. The provinces of Hungary which are richest in mineral waters, are those situate at the north-west extremity of the basin, among the mountains grouped around the colossal peak of Tatra, the highest of the Carpathians, and in the prolongation of the Styrian Alps towards Presburg and Buda. On the banks of the Lake of Balaton are the acidulous springs of *Fured*. The vast arid and marshy plains in the centre of the country, which are so remarkable for their nitre and natron lakes, are totally destitute of true mineral waters; and they only re-appear on arriving at the cluster of mountains on the south-east frontiers of Hungary and Transylvania, where we have the ancient hot-baths of *Mehadia*, the Solfatara of *Budos*, and the adjoining hot sulphureous chalybeate springs at *Reps* and *Vasarhely*. Chalybeate-sulphureous springs are said by Boué to abound at the base of the range of mountains which separate Transylvania from Moldavia; and acidulo-chalybeate still more. The most celebrated of the latter are those of *Borsah*, much resorted to for their medicinal virtues, and which are said to contain more carbonic acid than even the Pyrmont waters. Scattered over the district of *Klausenburg* are innumerable salt-springs, which are doubtless connected with those, the only mineral waters found in the eastern Carpathians.

The mineral waters of the north of Germany consist merely of a few cold chalybeate, brine, and sulphureous springs. The most noted are the chalybeates of *Uhlmuhl* in Hanover; *Amalienbad* in Brunswick; *Bramstedt*

<sup>1</sup> Voyage en Hongrie, 1822, i. 116.

in Holstein; *Goldberg* and *Doberan* in Mecklenburg; *Potsdam*, *Freienwald*, *Frankfurt*, *Gleissen*, in Brandenburg; *Muskau* in Lusatia: the sulphureous springs of *Schmeckwitz* in Saxony; of *Doberan* in Mecklenburg; *Oldeslohe* in Holstein; and the brine-springs of *Oldeslohe* and *Bramstedt* in Holstein; *Goldberg*, *Doberan*, and *Greifswald* in Mecklenburg; *Radeberg* in Saxony.

Italy is remarkable for the number of its thermal, acidulous, and sulphureous waters; and in many situations carbonic acid and sulphuretted hydrogen are discharged from the bowels of the earth, uncombined with water at all. They almost all emerge from the valleys at the foot of the different mountain ridges. We have already seen the position of the numerous sulphureous springs of Piedmont, and the same general character continues to prevail in the springs of Lombardy and the Apennines. Another remarkable fact is, that in the prolongation southwards of the Italian peninsula, all its mineral waters are met with on the Mediterranean side of the Apennines, none on the Adriatic, a phenomenon which we shall afterwards see to be intimately connected with the position of the volcanoes, and other manifestations of subterranean fire of this country. In Lombardy are the well-known hot sulphureous springs of *Albano* and *Acqui*, on the northern declivity of the Apennines, whose predominant solid constituents are muriate of soda and earthy sulphates; the former contains also the sulphate of soda;—to which may be added the hot and cold sulphureous waters of *Ravanasco*, *Capinasco*, *Castelletto d'Orba*, *Ponti*, *Lepame*, and *Visone*, which possess a very analogous composition. To these may be added the acidulous chalybeate of *Recoaro*, which contains also the carbonate and sulphate of lime. In Parma are the cold sulphureous springs of *Lessignano*. On proceeding southwards into Tuscany, the mineral waters are found exclusively on the opposite side of the Apennines. The hot-baths of *Lucca* contain, as their principal ingredients, different sulphates, with a small quantity of carbonic acid; those of *Pisa*, the sulphates

of lime, magnesia, and soda; of *Monte Catini*, carbonic acid, sulphates of lime and alumina, and muriate of soda; the sulphureous thermals of *Volterra*, carbonate of lime, sulphate of soda, iron, and silica; of *San Filippo*, much carbonic acid, sulphate and carbonate of lime; and the *Bagni di Vignone*, not far from the preceding, which are quite free from all sulphureous impregnation, but discharge large volumes of carbonic acid with violent ebullition, and deposit large quantities of calcareous matters. Besides these, Tuscany contains the thermal waters of *San Casciano*, near Florence; the cold sulphureous springs of *Montalceto*. Nearer the central ridge of the Apennines, are the acidulous springs of *Asciano*, with the sulphates of lime, magnesia, and soda; and of *Montione*, near Arezzo, with muriate and carbonate of soda; and other acidulous springs in the vicinity, which have been examined particularly by Fabroni. The only chalybeate of note in Tuscany is that of *Chitignano del Rio*, which is strongly impregnated with carbonic acid and carbonated earths.

The celebrated sulphur lagunes of Tuscany, which deposit sulphur and sulphuric salts, situated a few miles SW. of Volterra, near Monte Rotundo and Monte Cerboli, are simple cavities at the bottom of the valley, which are filled by rain-water. Sulphuretted hydrogen escapes through many fissures in the rock, and raises the water to the boiling temperature. The gas carries along with it boracic acid, only found besides at Vulcano in the Lipari Islands. The rock from which the gas issues is limestone.

In the Papal territory, the acidulous springs of *Nocera*, with the carbonate of lime, are also found near the ridge of the Apennines: they are not very largely impregnated with carbonic acid, but contain a proportion of azote. The sulphureous thermals of *Viterbo* and *Porretta* both contain carbonic acid and carbonate of lime. At *Civita Vecchia*, on the shores of the Mediterranean, are hot saline waters. The chalybeates of *Civillina* differ in composition from most of the mineral waters of



Italy, in their predominant constituent being the sulphate of iron, associated with the sulphates of lime and magnesia.

This conducts us to the fire-torn soil of Campania, which the researches of Brieslak have shown to emit almost at every point noxious gases, steam, and hot springs. The most remarkable of these exhalations are the sulphureous vapours near *Pozzuoli* (Stufe di Nerone), and of *St Germano* near the Lago d'Agnano, which have been long celebrated for their medicinal virtues. The greater number of the mineral waters of the environs of Naples are also of the sulphureous class. The principal are those of *Pozzuoli*, with the carbonates of lime, magnesia, and alumina, some iron, and the muriate and sulphate of lime; of *Pisciarelli* and *Contursi*, with carbonic acid, and nearly the same solid ingredients; and, lastly, the sulphureous thermals of *Castellamare*, near which are many cold sulphureous chalybeates. Sulphuretted and acidulated waters are found near *Atella*, on the west side of Mont Vultur, which has a crater, and is covered with lava, with leucite and hæüyne. At the bottom of the crater are said to be lakes impregnated with carbonic acid, and which emit an inflammable gas.

The thermal waters at *Thermopylæ* in Greece, deposit a copious calcareous incrustation. They hold, in solution, carbonic acid, lime, muriate of soda, and sulphuretted hydrogen.

The whole of the north of Russia presents a remarkable deficiency of mineral waters, in which we cannot mistake the analogy of the plains of Brandenburg and Poland; but the southern parts of this great empire contain a considerable number. A series of salt springs is ranged along the banks of the Volga, so remarkable for their salt lakes and rock-salt deposits. Many hot springs issue forth from the Caucasian Mountains in the Asiatic portion of the empire.

The great Scandinavian peninsula is possessed of an extensive range of mountains, but we are yet uninformed of its containing any warm spring; and its cold mi-

neral waters are for the most part but weakly impregnated with solid matters, as if nature had impressed upon this land a deeper seated source of frigidity than even the severity of its climate.

Having thus sketched out the great outline of the geographical distribution of the mineral waters of the mainland of Europe, let us take an equally rapid view of their position in its circumjacent islands.

It is in the island of Iceland that the phenomena of hot springs are seen in all their magnificence, and where they present the most interesting facts to the industrious searcher into the mysteries of their origin. Almost every point of this great island which has as yet been explored, emits steam and hot springs with every degree of temperature, from the common atmospheric up to the boiling point. When cold, or when their temperature falls below a certain point, they generally contain carbonic acid, with very few other foreign ingredients. We have thus the acidulous spring of *Öl-kilda*, with a temperature of 45° F.; and, near *Lysiehouls*, there issues from a calcareous mound a spring with a temperature of 96°, which has a strong acidulous taste<sup>1</sup>. When, however, their temperature rises above a certain point, they are remarkable for possessing the power of holding in solution those substances of all others deemed most insoluble, as silica itself. Those with which we are best acquainted are in the south-west portion of the island. The most remarkable are the hot springs in the valley of *Reikholt*, with its singular alternating Geyser; the spouting springs of *Reikum*, on the banks of the Elvas: but, above all, the *Great Geysers*, to the north of Skalholt, certainly worthy of being ranked among the wonders of the world. In the two last, which have been carefully analyzed by Dr Black, the silica amounted to nearly one-half of all the solid constituents (see p. 25, note), and is associated chiefly with the muriate and sulphate of soda. Sulphuretted hydrogen, as far as we yet know, does not seem to be a very frequent or abundant

<sup>1</sup> *Sir G. Mackenzie's Travels in Iceland*, 1811, pp. 162. 169.

ingredient in the Icelandic springs. The Rykum little Geyser, communicates to meat boiled in it a strong taste of sulphur, the only way in which its sulphureous impregnation can be discovered; and some of the smaller springs in the same valley line their channels with a thin incrustation of the same mineral<sup>1</sup>: and near *Reikiavik* is a spring with a temperature of 188° F., which has a weak sulphureous smell, which it communicates to plants taken out of the water. In the sulphur mountains of *Krisuvik* are remarkable springs of boiling mud; and, although there are prodigious deposits of sulphur in the surrounding argillaceous soil, we are not informed that any of the almost innumerable hot springs are remarkable for their sulphureous impregnation.

The interior of Iceland presents one vast untrodden desert, whose existence is only recalled to the recollection of the inhabitants, when the Shaptaa, or some of the other jokuls which rear their lofty heads amidst these solitudes, pour forth their devastating torrents of mud and hot water upon the scanty products of their ungenial soil.

We are, however, informed, that many of the lakes scattered over the central and eastern districts of the island were formerly tracts abounding in hot springs, which have since fallen in and formed the hollows now occupied by the water of the lakes<sup>2</sup>; a fact which is rendered very probable by the numerous proofs presented by the Geysers and other springs, that the thermal waters of Iceland have formerly been of much greater extent, and played a much more important part at some former epoch of her physical history. Even now, there are said to be many hot springs near the *Lake Myvatn*, in the north-east of the island, which rival the Geyser in the magnificence of their phenomena, and continue their operations with much greater regularity.

Britain, for its extent and its great variety and interest in a geognostical point of view, may be said to pos-

<sup>1</sup> *Stanley's Account of the Hot Springs of Rycum*, in *Edin. Phil. Trans.* 1794, iii. 131.—<sup>2</sup> *Menge's Mineralogical Journey in Iceland*, in *Edin. Phil. Journal*, 1820, ii. 166.



sess very few thermal waters, although it is not without its full share of cold mineral springs, chiefly of the sulphureous, saline, and chalybeate classes; but very few alkaline or acidulous.

In Scotland no warm springs have yet been discovered, although in many points it resembles many districts of the continent where they are tolerably abundant. Can this be considered as an additional analogy to those which have already been traced between the northern parts of this island and the opposite coasts of Scandinavia? Its two chief sulphureous waters are those of *Strathpeffer*, near Dingwall in Ross-shire, whose solid ingredients are in the order of quantity, sulphate of soda, sulphate of lime, muriate of soda, and a little of the sulphate of magnesia. Similar springs abound in the adjoining country, there being some at *Muirtown*, about two miles south-west of Strathpeffer, and another has been discovered about fifteen miles to the north-west. The second is that of *Moffat* in Dumfriesshire, which contains muriate of soda in large quantity, sulphate of soda, sulphate of lime, and a little sulphate of magnesia, with carbonic acid and azote. The chalybeate waters which have been most celebrated for their medicinal virtues are those of *Hartfell*, which issue from the base of the mountain of the same name near Moffat. There are two springs, the Hartfell Spa, or *saline chalybeate*, with the sulphate of iron, muriate of lime, and a trace of the sulphate of alumina; and the *aluminous chalybeate*, which, like all springs of this character, is very strongly impregnated with solid matters, which are sulphate of iron, sulphate of alumina, and an excess of sulphuric acid. Another aluminous chalybeate situate at *Vicar's Bridge* near Dollar, would hardly merit notice, were it not the most strongly impregnated natural solution of this class with which we are acquainted: its constituents are sulphate of iron in very large proportion, sulphate of alumina, sulphate of magnesia, sulphate of lime, and a minute quantity of the muriates of soda and potash. Besides these, there are many other chalybeates which have been at different times in repute, as at *Peter-*

*head* in Aberdeenshire, at *Bonnington* near Edinburgh, and many others. This last spring is principally remarkable in the history of mineral waters, as being the first in this country in which iodine was detected by Mr Copland: its ingredients are iron held in solution by free carbonic acid, the sulphates and muriates of soda, lime, magnesia, potash, with a small quantity of the hydriodate of potash. The chief saline waters of Scotland are those of *Dunblane* near Stirling, classical in the history of mineral waters ever since the labours of the late Dr Murray on the combinations of the constituents of saline springs: their ingredients are stated by this chemist to be the muriate of soda, muriate of lime, sulphate of lime, a minute proportion of the muriate of magnesia, with a little carbonic acid: Of *Airthrey*, about eight miles from the former, which contain the same salts, and in the same relative proportions, but in much larger quantity: Of *Pitcaithly*, on the banks of the Earne near Perth, with the muriate of soda, muriate of lime, sulphate of lime, carbonate of lime, and carbonic acid: And, lastly, those of *Innerleithen*, on the banks of the Tweed near Peebles, which, according to the analysis of Dr Fyfe, contain muriate of soda, muriate of lime, and carbonate of magnesia; the large quantity of the last of these ingredients (seven parts in 10,000 of water) renders it probable that it must contain a quantity of carbonic acid sufficient to constitute an acidulous spring, in order to be capable of holding the earth in solution. The only water in which the carbonic acid can be said to constitute an acidulous spring is that of *Kilburn* near Moffat, in which this gas is associated with a little sulphuretted hydrogen; and, as solid ingredients, the sulphates of soda, magnesia, and lime, with a smaller quantity of carbonates of lime and magnesia, muriates of soda, lime, and magnesia, and the oxide of iron.

In England, the thermal waters may be said geographically to constitute two distinct groups,—a northern in the county of Derby, and a southern on the banks of the Avon on the borders of the counties of Gloucester

and Somerset. The temperature of the northern group is very inconsiderable: its chief springs are *Buxton*, situate in the northern angle of Derbyshire, at the foot of a chain of hills which separates it from Cheshire; it is a calcareous water, although it contains but a small proportion of foreign matters, which are carbonate of lime, muriate of soda, with a minute proportion of sulphate of lime and muriate of magnesia, along with azote and a little carbonic acid; besides the tepid waters, Buxton possesses a weak chalybeate: the next is *Matlock*, two miles distant from the former, on the banks of the Derwent; this is also a calcareous water, and approaches still nearer a state of purity than the preceding, its chief ingredients being free carbonic acid and some muriates and sulphates of lime, magnesia, and perhaps soda. In the southern group we have the ancient waters of *Bath*, the hottest of the springs of England, whose celebrity extends even to the age of the Romans; there are three hot springs varying slightly in temperature, but all containing the same ingredients, differing only in the degree of impregnation. In the King's Bath, the constituents are the sulphate of lime, the carbonate and sulphate of soda, and minute quantities of the carbonate of lime, silica, and oxide of iron: from its high temperature it holds but a small quantity of gaseous matter in solution, consisting of carbonic acid, but there rise from the soil out of which the springs issue, copious bubbles of a gas which was long supposed to be solely carbonic acid, from its effect on lime water, but which was ascertained by Priestley to contain but five per cent. of this acid, the rest being entirely azote. The other thermal water of the group is the *Bristol hot well*, situate at the bottom of St Vincent's Rock, a lofty cliff on the Gloucester side of the Avon, about a mile below the city; its temperature is much inferior to that of Bath, and it contains a much smaller quantity of solid matters, but considerably more carbonic acid, than any of the other thermal waters of the country; its salts are carbonate of lime, sulphates of lime and soda, muriates of magnesia and soda.



The only thermal water known in Wales is that in the valley of *Taafé*, about six miles north of Cardiff in Glamorganshire.

Following the principles which I have adopted in this Essay, of considering the predominant constituent as that characteristic of a mineral water, the cold springs of England are referable to the sulphureous, alkaline, purging, saline, brine and chalybeate classes; but here, as everywhere else, one spring often unites the characters of several of these classes, the principal difficulty being to define what quantity of gas should be considered as constituting a sulphureous or an acidulous water, when a large quantity of other more fixed substances are present.

The chief sulphureous waters are:—*Gilsland* in Eskdale, Cumberlandshire, whose chief solid ingredient is the muriate of soda; in the vicinity is a chalybeate spring: *Butterby* in Durham, with carbonic acid and azote, the muriate of soda, muriates of lime and magnesia, carbonate and sulphate of lime: *Harrowgate* in Yorkshire, with carbonic acid, azote, and carburetted hydrogen; a large quantity of muriate of soda, with muriate of magnesia, muriate of lime, carbonates of lime and magnesia: *Holbeck* near Leeds, with some azotic gas: sulphur water at Leamington, in Warwickshire, with muriate of soda, sulphate of soda, muriates of lime and magnesia: many of the Cheltenham saline waters are weakly impregnated with sulphuretted hydrogen: Llandridod in Radnorshire, with some carbonic acid and a large quantity of muriate of soda.

*Malvern*, at the bottom of the hills of the same name, in Worcestershire, is the only alkaline water of this country, in the true sense of the term; but the quantity of carbonate of soda is very small, associated with a little of the sulphate of the same base, and the carbonate of lime.

The principal purging waters are:—*Scarborough*, on the coast of Yorkshire, which contains, besides the sulphate of soda, a little sulphate and carbonate of lime and oxide of iron; there is here another water, a simply

carbonated chalybeate:—*Cheltenham*, in the county of Gloucester : among the great variety of springs which emerge from this sandy vale, the sulphate of soda predominates in some and the muriate in others, their quantities are, however, generally nearly equal; these are associated with the sulphates of soda and magnesia : some of the springs contain oxide of iron, some, as before mentioned, a slight sulphureous impregnation, and some a little carbonic acid; but none of these constituents are constant in their quantities and relative proportions, and many of the latter are often absent altogether.

Among the saline waters the principal are:—*Leamington*, in which, as at Cheltenham, the muriate and sulphate of soda alternately predominate, associated with the muriates of lime and magnesia, and, in some of the springs, a minute proportion of oxide of iron:—*Gloucester*, with the sulphates of soda and lime as subordinate ingredients : one of the springs contains a trace of sulphuretted hydrogen, another of oxide of iron:—*Epsom* in Surrey, in which the sulphate of lime is the principal ingredient, along with the muriate of soda, carbonate of lime, and sulphate of soda:—*Llandridod* in Radnorshire, in which the muriate of magnesia is the chief constituent, along with the muriate of lime.

The brine springs of England form two principal series:— a smaller and more northerly, in the county of Durham, south of Newcastle : the southern is much more extensive, being distributed over the counties of Cheshire, in which the principal are at *Middlewich* and *Nantwich*; Staffordshire, at *Shirleywich*; Worcestershire, at *Droitwich*; in all of which the impregnation is very considerable, amounting in most cases to saturation; the quantity of muriate of soda is much more inconsiderable in those of *Kingswood* near Bristol, of *Bualt* in Radnorshire, and of the celebrated springs of *Ashby-de-la-Zouch* in Leicestershire, many of which approach very much in their characters to the saline waters, as they contain, besides the muriate of soda, a considerable quantity of the muriate of lime.

The only springs of consequence in which the salts of

iron predominate are the carbonated saline chalybeates of *Tunbridge*, on the southern borders of Kent, in which the oxide of iron is associated with the muriate of soda, sulphate of lime, small quantities of the earthy muriates and carbonates, and traces of manganese: and the aluminous chalybeate on the south coast of the *Isle of Wight*, which contains, besides the sulphates of iron and alumina, the sulphates of soda, lime, magnesia, muriate of soda, and a minute quantity of silica: there is another aluminous chalybeate with a very analogous composition at *Horley-green*, near Halifax, in Yorkshire, but which is not much more than a third of the strength of that in the Isle of Wight.

Ireland possesses but one thermal water, of very inconsiderable temperature, that of *Mallow*, in the county of Cork, which resembles in composition that of Bristol, on the opposite shore of the Channel, containing carbonic acid, carbonate and sulphate of lime, muriate and sulphate of soda, and sulphate of magnesia. Almost all the other mineral waters are cold sulphureous, chalybeate or saline waters. A few contain carbonic acid in excess; such as those of *Johnston*, in the county of Kilkenny; of *Castlecomer*; *Brownstown*, which resembles the Cheltenham waters very much in its sensible and medicinal qualities. The chief sulphureous waters are those of *Lucan*, in the county of Dublin; several in the county of Leitrim; *Swadlinbar*, in the county of Cavan, the strongest in Ireland, with the carbonate and muriate of soda, and the sulphate of magnesia; several in the county of Fermanagh. The principal chalybeates are:—*John's Well*, in county Kilkenny; *Killeshan*, in Queen's County; *Wexford Spa*; *Castleconnel*, in county Limerick; *Castlemain*, in county Kerry; *Crosstown*, in county Waterford; *Galway Spa*, said to resemble Tunbridge waters; *Athlone*, in county Roscommon. Of the saline those most worthy of notice are:—several in the vicinity of *Dublin*; *Cape Clear* water; *Maherahey*, in county Kerry; *Clonmel Spa*, in county Tipperary, is said to cure scrofula; *Carrickmore*, in county Cavan; *Newton*



*Stewart*, in county Tyrone ; *Kilroot*, in county Donegal ; *Antrim Spa* ; *Dromore*, in county Down.

Several of the islands in the Mediterranean are remarkable for the number and high temperature of their thermal springs.

In the Island of Majorca there is a sulphureous thermal spring in the district of the town of *Campos*.

In Corsica are the warm sulphureous springs of *Guittera* ; and the cold sulphureous waters of *Puzzichello*, which contain, besides sulphate of lime, as the principal ingredient, some carbonic acid, oxide of iron, silica, and alumina.

Sardinia also contains many hot and cold sulphureous springs, but of which our information is exceedingly scanty, as the greater number are entirely neglected as curative agents ; such as those of *Fordingianu*<sup>1</sup>, *Fluminimajor*, and *St Antiogo* ; to which may be added those of *Sardara* (139°), *Acqua Cotta*, near Villa Cedro (105°), *Coquinas* near Castel Doria (159°), at *Dongali*, *Codrongianas*, the *Bennetutti* springs in the mountains of Goceano, and the thermals of *Marrubiu*, *Iglesias*, and *St Antonio*.

The little Island of Ischia, at the mouth of the Gulf of Naples, can only be compared with the adjacent coast of Campania, or the Island of Iceland, in the character, number, and high temperature of its hot springs. The substances held in solution are chiefly the carbonate, sulphate, and muriate of soda ; the last is the most abundant constituent, especially in those situate in the lower parts of the island, near the sea shore : those in the interior contain much less of it, except one or two, such as those of Cappone near Gurgitello<sup>2</sup>. All are impregnated with carbonic acid, and some with a little sulphuretted hydrogen, but which is very fugitive, and can only be detected by the smell. Several, as the springs of Olmitello, contain free muriatic acid. Alumina, in

<sup>1</sup> Captain *Smyth* observes (Sketch of Sardinia, 1828, p. 77), that these waters, situate on the left bank of the Tirsi, are quite limpid and tasteless ; although there are still to be seen the remains of the Forum Trajani and sulphureous baths for which it was formerly celebrated.

<sup>2</sup> *Siano*, Storia dell' Isola d'Ischia, p. 31

union with iron, is a very common ingredient in small quantity. Almost all the hot springs contain a minute proportion of silica. Sub-borate of soda is found in the *Acqua san Restituta*, and sulphate of potash in that of *Olmitello*. The greater number issue forth from different heights on Mount Epomeo. The hottest are those *delle Petrelle* which reach the boiling point; next in order are those of *Fontano*, *Fornello*, *S. Restituta*, *S. Montano*, *Citara* with a temperature of  $122^{\circ}$  F.; of *Gurgitello*, *Colata*, *Rete*, *Capillo*, at  $145^{\circ}$ ; and *Nitroli*, *Olmitello*, *Capone*, at  $91^{\circ}$ . Those most celebrated for their medicinal uses, and which have been most carefully analyzed, are *Gurgitello*, *San Restituta*, *Fontana*, *Fornello*, and *Olmitello*, the last of which contains the smallest quantity of solid matters<sup>1</sup>. Besides these thermal waters, this island is famous for its gaseous springs or fumaroles, which are much used for medicinal purposes. Their principal constituents are aqueous vapour, impregnated with the carbonic, muriatic, and hydrothionic acids. Those most frequented are the *Stufa di Testaccio* ( $88^{\circ}$  F.), and of *Fasano* on Mount Epomeo, about 200 feet above the level of the sea; the *Stufa san Lorenzo* ( $111^{\circ}$ ); *Castiglione* ( $122^{\circ}$ ); and *Cacciotto* ( $145^{\circ}$ ); this last is said constantly to emit a sound resembling the beating of a drum.

Some hot springs are said to exist in the Island of Lipari, about four miles west of the town<sup>2</sup>.

There are a vast variety of mineral waters almost throughout the whole of Sicily. Many of them are said to be boiling hot<sup>3</sup>, but of very few do we possess precise descriptions, and scarcely any one has been analyzed. At the bottom of Etna are the sulphureous springs of *Santa Venera*, near Jaci Reale. About half a mile to the west of *Palermo*, many warm springs rise from the bottom of the sea, at the depth of five or six feet. On the south-west side of the island are the ancient baths of Selinus, near the modern *Sciacca*, on the slope of

<sup>1</sup> *Wenzl*, in *Medicinisch-Chirurgische Zeitung*, September 1830.—

<sup>2</sup> *Daubeny's Description of Volcanoes*, 1826, p. 189.—<sup>3</sup> *Brydone's Tour through Sicily and Malta*, 1773, vol. ii. p. 271.

Mount Calogero, which, in sensible properties, very much resemble the Harrowgate waters, and hence probably contain, besides sulphuretted hydrogen, the sulphate of magnesia. Numerous salt springs are found in this quarter of the island, which Dr Daubeny found, by the application of tests, to contain muriate of soda, and the sulphates of magnesia and soda. I need hardly recal to the reader's recollection the well known mud volcano of Macaluba, near Girgenti, which continually disengages copious volumes of a gas consisting of a mixture of carbonic acid and carburetted hydrogen, sometimes with such violence as to project the mud to a height of 200 feet.

Many copious boiling springs (the only springs of water in the island) issue from the arid heights of *Pentelaria*; and near the centre of the island is a lake which fills the cavity of an ancient crater; its waters are tepid, saline, and contain no fish<sup>1</sup>. It is formed by the accumulated supply of numerous hot springs.

The Grecian Archipelago is not without its mineral waters. In the Island of Milo, the whole neighbourhood of the port abounds in hot sulphureous and chalybeate springs. The most celebrated are the baths of *Loutra*, said to contain a strong saline impregnation; and those of *Protothalassa*, situate close to the sea shore. It is worthy of remark, that, on the opposite peninsula of Argolis, there are hot springs in the vicinity of *Methone*, which are said to tinge their bed with an ochry deposit.

Mytilene, also, on the coast of Asia Minor, possesses mineral waters, resorted to by the inhabitants for different complaints.

Having now finished this imperfect outline of the great features of the mineral waters in our own continent; it now remains to trace out their distribution in the three remaining quarters of the globe. Whenever we leave Europe, however, our data immediately become scanty and imperfect; for, although we have travelling

<sup>1</sup> *Malte Brun*, Geog. Univ. Eng. Trans. vii. 603.



geologists, zoologists, and botanists, it is only very recently that this department of natural science has been divested entirely of the metaphysics and mystery which it inherited from the middle ages, has taken its true place in the catalogue of human knowledge, and has consequently become a subject for the positive observations of the scientific traveller. Our information regarding exotic mineral waters is almost exclusively confined to those of the thermal class, which have attracted especially the attention of man in all ages, and at every stage of civilization; but, even with regard to these, the sum-total of our knowledge seldom goes beyond a few scattered notices of their temperature and most obvious sensible properties. Their detailed analyses, or even the very simple process of the application of a few reagents, is what very few travellers seem to have at all thought of, far less their dispersion in distinct groups, their relations to the nearest chains of mountains and oceanic basins, and many others of equal interest and importance.

## ASIA AND ITS ISLANDS.

AT the north-west extremity of Asia Minor, in the ancient Bithynia, are the baths of *Pythia*, beyond Mount Olympus. In the plain of Troy, on the banks of the River Mender, are fountains which issue forth with much impetuosity near the village of *Bonarbashy*, supposed by M. Chevalier to be one of the sources of the ancient Scamander, described by Homer under the appellation of “*λαρῆς*”<sup>1</sup>, and which Dr Clarke found to possess a temperature of 62° F., and to be covered with a cloud of condensed vapour, in consequence of the comparative coolness of the external air (46°), exactly as described by the ancient poet<sup>2</sup>. Many such springs, of dif-

<sup>1</sup> Iliad, xxii. 149.

<sup>2</sup> Travels, 8vo. 1817, iii. 142. Whether these fountains merit being ranked among thermal springs can only be determined by a knowledge of the mean temperature of the plain of Troy. In want of correct observations, according to Mayer's formula, the mean temperature of lat. 40° at the level of the sea is 62°.6 F.

ferent degrees of heat, issue forth from the foot of Mount Gargarus, and all along the valley of the Mender from Mount Ida to the Hellespont<sup>1</sup>. Farther south, in the midst of the ruins of Alexandria Troas, on the shores of the Ægean, are the hot baths of *Lidja Hamam*, described by Dr Chandler<sup>2</sup>, with a temperature of 142°, and said to be impregnated with iron and salt. The ruins of the different baths and aqueducts still remain to attest their former magnificence; and they are even now much used by the inhabitants for cutaneous disorders. At *Smyrna* are very ancient baths, described by Strabo. At *Capliza*, in the Levant, are baths, described by Tournefort<sup>3</sup>, which are much frequented by the Turks; the vapours which they exhale have a strong sulphureous smell, and the walls of their channel are lined with an ochry sediment.

Not far from the town of *Tiberias* in Syria are four hot springs<sup>4</sup>; one of them is sulphureous, and has a temperature of 200° F.; two of the others deposit a ferruginous sediment. Arabia, which has been often celebrated by the poet for its almost entire destitution of the element most necessary for the support of animal and vegetable life, as if by a sort of compensation, possesses sulphureous springs of a very elevated temperature in the district of the Hedjaz. Such are those of *Ain le Mousa*, between Cairo and Mount Sinai; and of *Hamam Faraoun*, which issue forth from the foot of a mountain of the same name<sup>5</sup>. And we are informed by Burckhardt that a great number of warm springs are found at almost every station of the road from Medina to Mecca<sup>6</sup>.

The great Caucasian isthmus would seem to be by no means destitute of mineral waters. Thus there are the well known hot springs of *Erzroum*, the capital of Armenia; and of *Eliza*, in the same country, described by

<sup>1</sup> At the base of Mount Gargarus, Dr Clarke found another spring with the same temperature 62°, close to which was one so low as 34°.

<sup>2</sup> Travels in Asia Minor, p. 33.—<sup>3</sup> See also *Spon's Travels in Italy, Dalmatia, the Levant, &c.*—<sup>4</sup> *Madden's Travels in Turkey, &c.* 1829, ii. 309.—<sup>5</sup> *Niebuhr. Description de l'Arabie*, 1774, p. 306.

—<sup>6</sup> Travels in Arabia, 1829, 8vo, ii. 220.

Tournefort. There are some also at *Teflis*, the capital of Georgia; and in the peninsula of Apscheron, so famous for its springs of naphtha, are many boiling springs, impregnated with a blue clay, and which are celebrated for their tonic virtues. Very lately some thermal waters have been discovered on the flanks of the colossal Elborus, at an elevation of 1400 feet above the level of the sea.

The mineral springs at the north base of the Caucasian range form two distinct groups<sup>1</sup>. The first, on the Beschtau group, extends north and south for nearly sixty versts in a straight line in an alluvial district, broken by trachyte hills, extending between Georgieffsk and Kislawodsk in the *Vorgebirge* of the Caucasus. In this group are found,—the warm sulphureous springs of *Piatigorsk* at the Maschuka; warm chalybeates at the *Eissenberg*; acidulous springs of *Narsanna* near Kislawodsk; cold sulphureous at the *Padkumok*; several alkaline springs in the same situation; cold chalybeate springs fifteen versts from Kislawodsk; and several tepid sulphureous springs at the foot of the *Kumgara*. The second, or the Terek group, extends along the coast formation, between the Terek and the mountains, at the foot of a range of sandstone hills. Here are found the thermal springs of *Catherine*, *Paul*, and *Peter*, in all of which the sulphate and carbonate of soda are the predominant ingredients, with a small quantity of free carbonic acid and hydrothionates. They are surrounded by ancient sinter deposits. The cold acidulo-chalybeate spring of *Bergtheer*, and the *Marienquellen*, probably resemble the Petersquellen, as they issue from the same sandstone chain.

The extensive range of Hindoo-Coosh, and its continuation in the Himalayahs, presents a wide, and, for the most part, hitherto untrodden field of research. Already several are said to have been discovered in the latter; and Hodgson<sup>2</sup> describes the very singular phenomenon of several at *Jumnotree*, issuing from beneath a

<sup>1</sup> *Hermann* in Poggendorff's *Annalen*, xxii. 344, 1831, No. 7.—

<sup>2</sup> *Asiatic Researches*, vol. xiv.



great arch in the perpetual snow, formed by the radiation from their heated surfaces.

On the elevated table-land of Tibet are many sulphureous and thermal waters, much resorted to by the inhabitants for their medicinal virtues. One of these, with a temperature of  $88^{\circ}$  F., is situate not far from the village of *Gangamaar*, and covers its channel with a white encrustation (calcareous?)<sup>1</sup>. There is another encrusting spring not far from the village of *Doahai*, in north latitude  $28^{\circ} 10'$ , which seems to possess alkaline properties.

At the base of a mountain near Ghassa, in Boutan, eternally covered with snow, is a spring so hot that few are capable of bearing the body immersed in it.

On approaching the plains of Hindostan, we find, thirty-five miles north of Delhi, the sulphureous thermal of *Sonah*, situate at the eastern base of the Mewat hills. At *Seetacoond*, near Chittagong, is a remarkable hot well, noticed in the Serampore reports (No. II.)

The Island of Ceylon is so closely connected to the Indian continent, that its springs must be ranged under the same system. About seven miles from Trincomalee are the hot springs of *Cannea*, the water of which is nearly quite pure, possessing the same specific gravity as distilled water, and Dr Davy<sup>2</sup> could detect only the slightest trace of muriate of soda, and a little carbonic acid and azote; a current of gaseous bubbles is observed at intervals to run from the basin of some of the wells, consisting of nearly pure azote, with a minute quantity of carbonic acid. The temperatures of these springs are subject to curious fluctuations, to the amount of three or four degrees in two or three hours, without any visible cause; it is not mentioned that, when hottest, the disengagement of gas is more copious than at other times. In the interior of the island are two springs in the *Bintenny*, sufficiently hot to dress vegetables, and one at *Welassey* too hot for the hand to bear; all of these constantly discharge gaseous bubbles, are of inconsiderable

<sup>1</sup> *Turner's Embassy to Tibet*, 1800, p. 220.—<sup>2</sup> *Account of the Interior of Ceylon*, 1831, p. 43.

specific gravity (1001.1 to 1000.5), and contain but minute traces of muriate of soda, carbonic acid, and vegetable matter. In Upper Ouva, at the altitude of 1861 feet above the level of the sea, is a thermal spring at *Badulla*, which also differs but slightly from distilled water (specific gravity 1000.8), in containing traces of common salt. Near *Alipoota* in the same country, is another thermal of a similar description. In other parts of the island are many cold chalybeates.

Siberia possesses many mineral waters, especially towards the Altaic and Daourian mountains. Besides the salt springs formerly noticed as abounding in the lower Volga, there are many at the base of the Uralian chain, north as far as latitude 50°. In the district of the Volga, there are also many chalybeate waters; the principal of these with which we are acquainted are those of *Zarizyn*, said to contain iron, but no acid, either the sulphuric or carbonic. About a verst from *Zarizyn* are springs which deposit an ochry sediment, and exhale an odour of petroleum. There is another of a nearly similar character near *Bannaia*, much used by the inhabitants in intermittent fevers. Near *Eschanka* is a spring said to be pretty highly charged with the sulphate of lime<sup>1</sup>; and the sulphureous springs of *Sarepta*, in the kingdom of Astracan, which contain a considerable quantity of the sulphate of soda. Near *Catherinebourg*, on the Asiatic side of the Urals, there are said to be many ferruginous waters, with some of the salts of sulphuric acid<sup>2</sup>. The vast steppes which extend north-east of the Caspian Sea, are full of lakes strongly impregnated with the sulphate of magnesia, which form a continuous chain extending from the Kuma and lower Volga to beyond the river Jenisei: these magnesia lakes are associated with natron waters; but we are as yet unacquainted with the mineral waters of this immense tract. Here, again, it would be curious to inquire if they are wanting in the great table land of central Asia, supposed to be elevated upwards of 10,000 feet above the level of the sea; or in

<sup>1</sup> *Pallas*, Voyages dans l'Empire de la Russie. French Transl. 1788-93. v. 322.—<sup>2</sup> *Malte Brun*, Geog. Univ. 1812, iii. 349.

the vast plains of Western Siberia; and if they are not accumulated along the northern base of the plateau, at its line of junction with the circumjacent plains. The few thermal waters with which we are acquainted in these regions, would seem to be confined principally to the vicinity of the Lake Baikal, situate at the very base of the Altayan mountains, and to the frontiers of Mongolia, in the high land of Daouria. Thus we have at the lake Baikal the hot springs on the banks of the Frelicka, at *Kotelnikowa*, and at *Bargusinsk*<sup>1</sup>, all of which possess a very elevated temperature. One of the springs which gives origin to the river *Chalon-Oussou*, on the frontiers of Mongolia, near the mountain of Abdoura, is a thermal spring which gushes forth with much impetuosity, and is strongly impregnated with sulphuretted hydrogen; another spring close by deposits a copious sediment, also with sulphureous smell: these waters are much resorted to by the Tongouses for their medicinal virtues in the form of baths. There is another hot spring near the sources of the *Tschikoi* river, on the borders of the mountains of Dasuria, near the lake Baikal, whose waters also exhale a sulphureous odour. At *Oulan Boulak*, near Nertschinsk, are mineral waters of some celebrity, which contain much sulphate of iron in solution. And, lastly, near the rivulet of *Pogromma*, in Daouria, are some acidulo-chalybeate waters, much used by the Bouriats, in whom they cause a temporary giddiness, and sometimes vomiting: these waters gave to M. Georgi a dram and a half of dry deposit in a Russian eimer of water, consisting chiefly of the carbonate and sulphate of lime, with a little of the oxide of iron, and a trace of sulphur<sup>2</sup>.

The mineral waters of China appear to be numerous and much frequented. Those with which we are chiefly acquainted are the thermal sulphureous springs of *Hongchan*, not far from the Yellow River; and some aluminous springs, described by Duhalde, six leagues to the north of Peking.

<sup>1</sup> *Georgi*, Description de la Russie.—<sup>2</sup> *Pallas*, Voyages, iv. 640, 652, 616, 254.



But of all the surface of the earth, it is probably in the semicircular chain extending from the peninsula of Malacca through Sumatra, Java, the Moluccas, the Japanese and Kurile Islands, north as far as the peninsula of Kamtschatka, that nature has made the most magnificent display of hot springs, as it is here that volcanic agency is seen exerted in all its grandeur. In Sumatra, hot springs are mentioned as existing in the vicinity of the Peaks of *Gonung Dempo* and of *Berassi*, which resemble the waters of Harrowgate in sensible properties. Some of the springs of this island contain much petroleum. There are thermal waters in the Island of *Cratoa*, in the Straits of Sunda. Many mineral springs, of various qualities, are found in different parts of the Island of Java. Those at *Cheribon*, on its northern coast, are among the most remarkable; the water issues from every part of a plain about 100 yards in diameter, exhales a strong sulphureous odour, and has a temperature of about 130° F. There is the well known stream of water, strongly impregnated with sulphuric acid, which issues from the crater of Mount Taschem, in the eastern quarter of the island, which, in the rainy season, flows into the adjoining White River, when it kills all the fish, and destroys the vegetation growing on its banks. Besides this, there are many other streams which issue from the craters of the numerous volcanoes of this island, impregnated with sulphurous acid. Most of the hot springs which issue forth on the coasts are highly charged with calcareous matter, which is copiously deposited in their channels in the form of various incrustations. On the south side of Java are many salt springs, which annually yield, by evaporation, large quantities of salt for the purposes of commerce. I may mention, that there is a remarkable mud spring, nearly in the centre of the Island<sup>1</sup>.

In the Island of Karuka, one of the Moluccas, Labillardiere describes hot springs, in the vicinity of which vegetation is remarkably vigorous.

<sup>1</sup> *Raffles' History of Java*, 1817, i. 23.

In Luconia are said to be a variety of hot baths, streams, and rivers, much used by the inhabitants in cutaneous disorders and other infirmities; the principal are those of *Bally* <sup>1</sup>. Every island almost of this immense group emits sulphureous vapours and boiling springs of various magnitudes, up to those of *Unsen*, near Simabara, in Japan, said by Kämpfer to possess a temperature of  $212^{\circ}$ , of which, in his account of that comparatively unknown country, he has given us such hints as would lead us to infer them to be the most remarkable hitherto known, not excepting the Geysers of Iceland. In the Kurile Islands, we have notices of hot springs in *Uschischir*, and thermal sulphureous waters in *Ikarma*. There are several hot springs in the peninsula of *Kamtschatka*, some of them of great size, which issue from its incessantly active and gigantic volcanoes. Some of them are sulphureous. No salt springs are said to have been yet discovered, notwithstanding the peculiar form of this peninsula; their chief solid matters appearing to be sulphates, as in that described by M. Lesseps, with a current one and a half feet deep, and six to seven broad, which also holds in solution much carbonate of lime. The same gentleman describes <sup>2</sup> a large sulphureous and saline hot spring, to the west of the Gulf of Pezina, which discharges itself into the River Tavatoma, near Okotsk. M. Kracheninnikow indeed affirms the rivers of that subpolar region never to be completely frozen over even in the depth of winter, and to furnish fish at that rigorous season <sup>3</sup>.

In the range of the Aleutian Islands, we find hot springs in *Kanaga* and *Unalaschka*. Warm springs appear to be scattered in several of the islands of the Pacific and Indian Oceans; among which I need only mention those in the Island of *Tanna*, one of the New Hebrides, where some are limpid, with a slightly astringent taste, and a temperature of  $191^{\circ}$ , while others are sulphureous, with a temperature of  $101^{\circ}$ , and discharge a large quantity of sulphuretted hydrogen at every explo-

<sup>1</sup> *Rutty's Synopsis of Min. Waters*, 1757, p. 589.—<sup>2</sup> *Travels in Kamtschatka*.—<sup>3</sup> *Voyage en Sibirie*, trad. de la Russe, 1778, iii. 347.

sion of the adjoining volcano<sup>1</sup>; and in *Amsterdam*, at the mouth of the Indian Ocean, where their temperature rises in some situations to 212°, many possess a ferruginous impregnation, which seems to increase in quantity the nearer we approach to the volcanic crater<sup>2</sup>; in different parts of the island, the pools and marshes have a very elevated temperature.

## AMERICA AND ITS ISLANDS.

This great continent possesses its full complement both of mineral and thermal springs; the latter seem to abound more especially in its southern half, as far at least as our scanty knowledge of the interior of its northern half can justify our instituting a comparison between its two great divisions. These issue forth both from stations high on its central Cordilleras, and from points of their lateral chains not very elevated above the surface of the sea.

*United States.*—Their thermal waters seem to be confined to a limited space,—limited when we take into account the vast extent of this country, at the foot of the ranges which bound the immediate basin of the Mississippi, between the latitudes of 34° and 38° north, extending through the States of Pennsylvania, Virginia, North Carolina, Tennessee, Arkansas, and Missouri. Thus, in the State of Pennsylvania, there are warm springs in the county of Huntingdon, and in the county of Alleghany, about 100 miles above Pittsburg. In the State of Vir-

<sup>1</sup> *Forster's Observations*, 1778, p. 47. A thermometer, buried to a small depth in the soil, rose to 210°.

<sup>2</sup> *Barrow's Voyage to Cochinchina*. "In different places," observes Mr Barrow, "we remarked a beautiful carpet of verdure, composed of a very fine moss, mixed with a species of lycopodium, and a variety of marchantia; the tufts of verdure floated on the surface of the warm mud, of which the temperature, at six or eight inches below the depth to which the roots of the plants extended, was 186°, which appeared the more curious, as this species of lycopodium appeared the same as that which grows in the middle of winter on the frozen heaths of the north of England. The whole soil trembled under our feet, and on applying the ear to the ground, a sound like boiling water was heard."



ginia, there are sulphureous warm springs near the sources of the James River, at the foot of the Alleghany Mountains, with a temperature of  $96^{\circ}$  and  $112^{\circ}$ ; and about 42 miles distant, in the county Botetourt, are the Sweet springs, with a temperature higher than that of common water. In the State of North Carolina, we have the thermal waters of *Buncombe*, with a temperature of  $104^{\circ}$  F.: in Tennessee, near the French Broad River, are springs so hot as to be unpleasant to the feelings, which are much frequented by invalids from the adjoining States of Georgia, Carolinas, and Virginia: in the territory of the Arkansas, near the sources of the *Washita*, six springs issue from the side of a hill, with the temperatures of  $150^{\circ}$ ,  $145^{\circ}$ ,  $136^{\circ}$ , and  $132^{\circ}$  F., they are said to possess no smell: in the territory of the Missouri, near the Snowy Mountains, are the *Wisdom* springs, said to be sufficiently hot to cook meat. Besides these, many other warm springs are said to exist in the Rocky Mountains<sup>1</sup>.

In the states which are extended along the shores of the Atlantic, are many cold springs, much resorted to for their medicinal properties. These seem chiefly referable to the acidulous, sulphureous, and chalybeate classes. Those most characterized by their carbonic acid impregnation are the springs of *Ballstown* and *Saratoga* in the State of New York, north of Albany, which contain upwards of three times their volume of carbonic acid, associated with a little sulphuretted hydrogen, and as solid constituents the muriate of soda, carbonate of lime, oxide of iron, and the muriates of magnesia and lime. Those of *New Lebanon* and *Rensselaer*, not far from the preceding, with a very analogous composition: an acidulo-sulphureous spring near *Litchfield* in the State of Connecticut: warm springs are said to exist near *Flushing* in Long Island. Sulphureous springs are still more abundant; the principal are—a deep sulphureous spring which issues from a cavern in *Rattlesnake Hill*, New Hampshire. There is another at the great bend of the Con-

<sup>1</sup> *Warden's Statistical Account of the United States*, 1819, iii. 169.

necticut river, said to disappear in one place and spring up in another, at intervals of two or three years. There are several in the State of New York, in its north-western portion, as at *Clifton* near Geneva; at *Litchfield* near Utica; and near *Newbury* on the west side of Snake Hill, which much resembles Harrowgate in its properties. There are four sulphureous springs in *Suffield*, State of Connecticut. In Pennsylvania are the *Cumberland* springs, which contain half their volume of sulphuretted hydrogen; the *York* springs, seventeen miles from Carlisle; and the *Yellow* springs in the county of Chester. In Kentucky are the *Olympian* springs near the sources of the Lecking river, one of which is said to contain iron, another sulphur, a third sulphur, salt, and carbonic acid; one near *Boonborough*. Near Harrodsberg in the same State is a spring impregnated with sulphate of magnesia. In South Carolina are the sulphureous springs of *Pacolet*, which also contain iron; and others on the south side of the *Paris Mountain*. Among the chalybeate springs we may notice two chalybeates in the State of Vermont, one at *Orwee* near Mount Independence, another at *Bridport*, said to contain sulphate of magnesia. In New York is the *Chappequa* spring at Mount Pleasant, near the Hudson river. In the State of Ohio is a chalybeate sixty-four miles from Cincinnati, which contains also much carbonate of lime.

Besides these there are many more<sup>1</sup>; but scarcely any have been analyzed, although they are much used medicinally; and we can only guess at their probable composition from the accounts given of their sensible properties and their effects. Thus, in South Carolina, there are the *Entaw* purgative springs in the district of Barnwell: and at *Schooley's Mount*, in the town of Washington, is a spring said to be efficacious in calculous disorders, which possesses a constant temperature of 52° F. in all seasons.

Another class of waters, however, the salt springs, remain to be noticed, regarding which our information

<sup>1</sup> Upwards of seventy are enumerated by Warden, in his Account of the United States.

is somewhat more precise, from their importance in a commercial point of view. They seem to be confined to the western side of the Alleghanies in the basin of the Ohio, extending through the States of Pennsylvania, Virginia, and Indiana. In Pennsylvania are the salt springs of *Cone-maugh*, of *Butter*, with 2.5 per cent. of saline matter; and at *Sinnemahoing* on the *Susquehanna*. In Virginia are the great salt works on the *Kenhawa*, about seven miles above its junction with the *Elk* river; and, in Indiana, salt springs are found on the *Wabash* river and at *Saline creek*, and near *New Lexington*. There are many petroleum springs in all this district, and encrustations of salts of magnesia and potash are very common on the canes in the State of Indiana, as near *Louisville*.

*Mexico*.—There are thermal waters (*Aguas calientes*) in *Guadalaxara*, west of *S. Luis de Potosi*. Those of *Chichimaquillo* in *Guanaxuato*, with a temperature of  $205^{\circ}$ ; of *Comangillo* near *Guanaxuato*, on the road from *Ovexeras*. And, lastly, in the valley of *Tenochtitlan*, are the saline thermals of *Nuestra Senora de Guadalupe*, and of *Penon de los Banos*, which contain carbonic acid, sulphates of lime and soda, and muriate of soda; from the last of which the Indians manufacture salt for domestic purposes<sup>1</sup>. *M. Humboldt* describes the emission of hot water and vapours from the table-land of Mexico at the volcano of *Jorullo*.

*South America*.—The illustrious *Humboldt*, to whom we owe so much of our knowledge of this very interesting quarter of the globe, describes those of *Trincheras* in *Venezuela*, as possessing the very elevated temperature of  $194^{\circ}$  F., with a strong impregnation of sulphuretted hydrogen<sup>2</sup>. Many other hot springs issue from the *Cordilleras* of *Venezuela*. The chief are those of *Provisor* near *St Diego* in *New Barcelona*; those of *Onoto* in the valleys of *Aragua* west of *Caraccas*, with a temperature of  $112^{\circ}$ , which discharge copious bubbles

<sup>1</sup> *Humboldt's* Political Essay on New Spain. Engl. transl. 1811, ii. 101.—<sup>2</sup> *Humboldt*, Voyage. Relation historique, 1819, ii. 78.



of azote from time to time from the bottom of the reservoir. In the mountains north-east of *Mariara*, are many hot sulphureous springs, with a temperature of  $147^{\circ}$ , much used by the inhabitants of the district for external affections, which also evolve azote, and contain much silica in solution<sup>1</sup>: some spring from the sea in the *Gulf of Cariaco*; some to the south of the *Rio Azal*; those of *Trapa* north-east of New Andalusia: some issue from *Mount Brigantin* near New Barcelona; those of *Cumacatar*: and there are boiling springs in the Sierra Nevada de Merida.

Near the town of Turbaco in the valley of the river Magdalena, are volcanitos or mud volcanos, the water at whose summits disengages at intervals a gas found to consist of very pure azote<sup>2</sup>. From the volcano of Puracé in the central chain of the Andes of New Grenada, issues the well-known *Rio Vinagre*, so remarkable for its sulphurous acid impregnation (see p. 35), which discharges itself into the Cauca, and exercises an equally destroying influence on the fish of that river, as the Java stream, formerly noticed. M. Humboldt found the waters of a subterraneous lake near the summit of the volcano to be saturated with sulphuretted hydrogen, and to precipitate slightly the nitrate of silver. Many other sulphureous springs and vapours emerge from fissures in the rock of the ridge of Quindin, between the basins of the Cauca and Magdalena; some of these possess a temperature of  $118^{\circ}$ <sup>3</sup>: and a small rivulet descends from the volcano of Tolima which exhales a strong odour of sulphuretted hydrogen. In the midst of these hot and sulphureous waters, however, others of a totally different character are found: near *Popayan* there are several saline springs, in which Dr Mill has detected the hydriodate of potash<sup>4</sup>; and Boussingault has analyzed saline waters at *Antioquia*, which he found to contain the muriates of soda, lime, magnesia, iron, and potash,

<sup>1</sup> Annales de Chim. et Phys. xxiii. 272. Boussingault and Rivero.  
<sup>2</sup> *Malte Brun*, Geog. Univ. 1817, v. 564. Humboldt, Atlas pittoresque, p. 239.—<sup>3</sup> *Humboldt*, Vues et Monumens, ii. 130.—<sup>4</sup> Journal of Royal Institution, N. S. iii. 384.

with traces of the hydriodate of magnesia and uncombined muriatic acid<sup>1</sup>. Salt springs are found surrounded with syenites at a great elevation near San Miguel in the Cordillera of Baraguan. A chain of salt springs may be traced for a length of more than fifty leagues in a direction from south-west to north-east, from the eastern Cordillera of New Grenada at Pinceima as far as the Llanos of the Rio Meta<sup>2</sup>.

Thermal sulphureous waters issue forth from the sandstone of *Cuenca* (Lat.  $2^{\circ} 53'$  S.), and from *Tollacpoma* near Caxamarca (Lat.  $7^{\circ} 8'$  S.).

Farther to the south we find in Upper Peru, thirty leagues from Guamanga, the well-known hot springs of *Guancavelica*, so remarkable for their deposits of calcareous tufa. Thermal waters are said to be not unfrequent on the western declivity of the southern prolongation of the Andes into Chili, from which flows the river Salado, so hot that it cannot be drank<sup>3</sup>.

Some mineral waters seem to occur in Surinam and Cayenne on the shores of the Atlantic. In the former is the cold acidulo-chalybeate water of *Savane*; and in the latter the chalybeate of *Baduel*.

*West India Islands.*—There are many hot springs in the inner range of the Antilles. In *St Lucia*, the principal are in a valley about a league north-east of the Soufriere, which give by analysis carbonic acid and sulphuretted hydrogen; the sulphate and muriate of soda, sulphate of iron, with some lime, alumina, and soda: others are found in different parts of the island, especially near the Petit Piton and in the bottom of the great Cul de Sac. When the orifice of discharge is narrow, some of the sulphureous waters have been found at their exit to possess a temperature of  $246^{\circ}$  F. In Martinique we have the *Font Chaud* near Fort Royal, with a temperature of  $122^{\circ}$ , much used in different diseases, and which contains carbonic acid, the carbonates of lime, alumina, and soda, the sulphate and muriate of soda, and

<sup>1</sup> *Alibert*, *Precis*, p. 500.—<sup>2</sup> *Humboldt*, *Gisement des Roches*, pp. 217. 134.—<sup>3</sup> *Rutty*, *Synopsis of Min. Waters*, p. 589.

the sulphate of iron; the springs of *Lamentin*, still hotter than the preceding: others about three-quarters of a league from Fort Royal; the springs called *Au François*, and some sulphureous waters at *Mont Pelée*. In Guadeloupe, the thermal waters are almost innumerable: the most remarkable are those of the *Ravine Chaude* in the northern part of the island, with a temperature of  $149^{\circ}$ , much used in cutaneous and rheumatic complaints; the *Eaux de Dole*, in the eastern part of the island, with a temperature of  $102^{\circ}$ ; the *Eaux Bouillantes* in the parish of the same name, on the west side of the island, at  $131^{\circ}$ ; those of *Mont de Voix* under the Soufriere, almost boiling hot; and many others. They abound also in *Monserat*, where they issue from the crater. In *Nevis* there are springs with a temperature of  $106^{\circ}$ , a little to the west of Charleston: in St Christopher's there are sulphureous springs at *Mount Misery*.

Mineral waters are not less frequent in the larger islands of the Greater Antilles. Numerous springs of different temperatures, chiefly of the sulphureous class, are found in Hayti; of these the principal, for the knowledge of which we are chiefly indebted to M. Moreau de St Mery, are the *Source Puante* in the quarter of the Croix de Bouquets; of *Cabouane* in the district of Tiburon, at  $100^{\circ}$ ; some in the parish of *Dalmarie* in the south of the island, at  $145^{\circ}$ ; in the quarter des Trois; those of *Mirebalais* on the banks of the Antibonite; the *Eaux de Banique* in the Spanish part of the island, at  $84^{\circ}$ : some on the mountains of *Viajama*, which appeared first after the great earthquake of the 18th October 1751: those of *Santiago de los Cavalleros* in the north of the island. To these thermal sulphureous springs may be added the chalybeates in the parish of *St Rose*, district of Mont Noire. In Jamaica, they are chiefly sulphureous and chalybeate, and rise from the sides of the mountains: the most remarkable are the sulphureous springs in *St Thomas* in the East, at  $123^{\circ}$ . In the great island of Cuba, the principal are those of *St Diego* in the west part of the island, at  $95^{\circ}$ , which contain sulphuretted hydrogen, carbonic acid, sulphates of soda and



magnesia, and some oxide of iron: of *Madruga*, with sulphuretted hydrogen, the carbonates and sulphates of lime and magnesia: of *Guanabacoa*, with the same principles as the former<sup>1</sup>.

#### AFRICA AND ITS ISLANDS.

As our geographical knowledge of the vast expanse of Africa is so very defective, a corresponding hiatus exists in that of its mineral waters.

Some are described by Desfontaines in the kingdom of Tunis. But those with which we are best acquainted are in the territory of the Cape of Good Hope: we have here the hot springs of *Brand Valley* at 144°, the water of which is quite tasteless, is used for domestic purposes, and forms no deposit in its channel; at the base of the ridge of *Zwarteberg* are some with a temperature of 118°, an ochry deposit in the channel, a chalybeate taste, and which contain some sulphuretted hydrogen; close to this hot-spring rises a perfectly pure cold spring: a chalybeate water at 108°, flows out of the *Cardouw* ridge into the Oliphant's river. In the district of *Graaf Reynet* on the banks of the Fish river, are sulphureous wells at 88°. Besides these there are thermal waters in the district of *Zwellendam*, behind the first ridge of mountains (chalybeates): in the valley of the *West Elephant* river: near the *East Elephant* river in Kamnasi land: behind *Kokman's Kloof*: and on the north side of the *Gariep* in Great Namaqualand. Cold mineral waters are found near *Graaf Reynet*, *Uitenhage*, and the *Tarka*<sup>2</sup>.

In the group of the Azores, sulphureous vapours and hot springs issue from many fissures in different parts of the island of *Terceira*<sup>3</sup>. The island of *St Michael* is famous for its hot springs, which are impregnated with sulphuretted hydrogen, sulphurous acid, and carbonic acid<sup>4</sup>; and in this respect are remarkably contrasted

<sup>1</sup> *Rubio*, Discurso sobre las Aguas, &c. Havan. 1817.—<sup>2</sup> See Barrow's Travels in South Africa, 1804, ii. 356. 364. 373; and Professor Jameson on South African Springs, in Edin. Cabinet Lib. ii. 1831, p. 388.—<sup>3</sup> System of Geog. 1747, ii. 513.—<sup>4</sup> Webster's Description of St Michael, 1822; and Edin. Phil. Journal, vi. 306.

with those of Iceland, to which they are in their physical appearances not dissimilar. The great quantities of water discharged from numerous orifices in the ground in the valley of Furnas, unite and form a considerable stream, which has been called the *Tepid River*. In the upper part of the valley are several basins of hot water or *caldeiras*, which are continually agitated by the disengagement of gaseous matter, said to be sulphuretted hydrogen. In the largest caldeira loud explosions are heard at intervals, which are always succeeded by a slight elevation of the water in the basin, a hissing noise, and an increased disengagement of sulphuretted hydrogen with sulphurous acid. There are also many cold mineral springs in the island which are abundant in carbonic acid and sulphuretted hydrogen; many are chalybeate, and deposit an ochry sediment in their channel.

The Canary Islands are remarkably contrasted with the Azores, in the almost entire want of thermal waters. We have formerly seen that they possess numerous acidulous springs (p. 93). Hot springs are, however, not altogether wanting: there is one of a very elevated temperature south of *Tazacorte* in the island of Palma, but it is generally covered by the sea, and its source can only be seen at very low tides. Some formerly existed on the point of Fuencaliente, but they were destroyed by the eruption of lava of 1678<sup>1</sup>.

All that we know of the great island of Madagascar is, that there are some strong mineral waters in the valley of *Amboulla*, described by Sonnerat<sup>2</sup>.

In the Isle of Bourbon are some sulphureous springs with a temperature of 100°, which issue from *Mount Salazes*.

With this I conclude this very rapid and imperfect outline of the great features of the geographical distribution of mineral waters. It has been my endeavour to adhere as much as possible to the positive description of those springs, of which we have tolerably precise infor-

<sup>1</sup> V. Buch's Beschreibung, p. 89.—<sup>2</sup> Voyage to the East Indies, 1782.

mation, and to abstain from theoretical conclusions, which in the present stage of the inquiry would be premature. This was more especially necessary in the examination of the extra-European thermal waters, as, if we were to include all the scattered notices existing of vapours and hot springs, which perhaps we might be quite justified in doing, it would amount to nothing less than a description of the volcanoes on the surface of our globe; and would involve us in a subject which, if not altogether extraneous to the subject matter of the present essay, has been separately treated of in many able works exclusively devoted to that topic.

There are, however, some relations which must of necessity have forced themselves on the mind of the attentive reader. He cannot fail to have been struck with the conformity of hot springs to the great mountain chains and groups which form what has been called the skeleton of our globe, whether these appear rearing their heads like the lofty Himalayahs, thousands of feet above the surface of its plains, or assume the form of submarine ridges, the summits of which only are seen constituting groups of islands prolonged from the adjacent capes and promontories. Cold mineral waters seem also to occupy different geographical positions, marked out by differences in chemical composition and their other relations. Springs, with the sulphate and carbonate of soda as their predominant constituents, approaching nearest to thermal waters in their connexion with mountain chains, and isolated rocky masses starting out of the general surface of a country. Saline and brine springs occupy a distinct position. And, lastly, cold sulphureous and chalybeate waters present, as it were, the most marked antagonism to thermal waters, in being found in the midst of extensive plains, and even in sandy tracts destitute of any solid strata, as in the plains of Pomerania and Poland. Leaving, however, these somewhat theoretical reflections, let us proceed to our next topic.



## SECTION II.

## TOPOGRAPHY OF MINERAL SPRINGS.

MANY of the topographical relations of mineral waters are included in the consideration of their geographical distribution : such as their latitude and longitude : their position in relation to the adjoining mountain ranges ; the proximity of the ocean, or other great masses of water. To complete our view of their position, there still remain the geological nature of the soil from which they issue ; and their elevation above the level of the sea. The first of these will form the subject of my next section. The latter will therefore be considered in the present. It will certainly not be an uninteresting subject of inquiry, whether the absolute or relative altitude of mineral waters has any influence upon their temperature, the nature or amount of their foreign constituents ; all their other relations remaining the same. To institute, however, such an inquiry in all its extent, there would be requisite a series of the elevations of mineral waters above the level of the ocean, which, from the causes which have been more than once alluded to, we are far from possessing.

*Relations of Altitude to the Temperature of Springs.*—In the Pyrenean range the only thermal waters with whose elevation we are acquainted, are those of Bagnères de Bigorre, Bagnères de Luchon, St Sauveur, and Bagnères<sup>1</sup>. That of the first is 1139 feet above the level of the sea, with a temperature of 122° ; of the second 2008, with a temperature of 145° ; of the third 2526, temperature 93° ; of the last 4259, temperature 122°. They are all situate at the bottom of the deep valleys of Baigorri, Luchon, Lavedan, and its lateral one of Bastan, surrounded on every side by lofty mountains, a feature which

<sup>1</sup> *Charpentier, Essai Geognostique sur les Pyrenees, 1823 ; p. 559, 564.*

is characteristic of many others of the thermal waters of the chain, such as those of Eaux Chaudes in the valley of Ossan ; Cauterets in another lateral one of that of Lavedan ; of Ussat and of Ax in that of the Arriege ; and of Oletta in that of Teta at the foot of Mont Canigou. In the same manner almost all the thermal waters of the Alps are situate at the bottom of valleys at various elevations. Those of St Didier and Courmayeur, in the valley of Aosta, at the foot of Mont Blanc, at 3750 feet ; of Leuk and Bryg in the valley of Rhone, at 4400 and 2184, with temperatures of  $124^{\circ}$  and  $86^{\circ}$  ; of Pfeffers in that of the Rhine, at 2128 ; and of Gastein, at the head of the valley of Salzburg, at 2939. The springs of Baden in Austria, and Baden in Baden, are at 638 and 616.

In France, the baths of Mont d'Or are at the elevation of 3139 in the valley of Dordogne, one of the three principal valleys which descend from this lofty mountain ; those of Clermont, at 1590 ; and of Plombieres in the Vosges, at 1368.

The hot springs of Karlsbad in Bohemia are situate at the bottom of the narrow and deep valley of the Teipel, at an altitude of 1180 feet<sup>1</sup>. The hot springs of Teplitz are at 720 feet. In Silesia, those of Landeck and Warmbrunn are at 1430 and 950. Those of Ems, Wiesbaden and Schlangenbad in Nassau, no more than 291, 323, and 870.

In South America the springs of Mariano, Onoto, and Guancavelica, at 1562, 2303, and 13,749.

From all these observations, it is abundantly evident, that the mere circumstance of elevation, considered absolutely, has no effect upon the temperature of springs. It is generally, however, found, that in any system of mineral waters connected with a group or chain of moun-

<sup>1</sup> The temperature of the hot springs of Karlsbad decreases in proportion to the increase of their elevation above the basin of the Sprudel. Thus, the Hygeia spring, which is also in the bed of the river Teipel, is  $159^{\circ}$  ; the Bernhardbrunn farther down the river, and elevated a few feet above its level,  $152^{\circ}$  ; Neuebrunn,  $141^{\circ}$  ; Muhlbrunn,  $133^{\circ}$  ; Theresienbrunn,  $127^{\circ}$  ; and the Schlossbrunn, at a considerable height on the west bank of the river, near the top of the town,  $116^{\circ}$ .

tains, the thermal waters, if any, are found at the bottom of the deep valleys or river beds, rarely (Leuk) on the declivities of the mountains, and scarcely ever seen near their ridge or summit.

*Relations of Altitude to their Composition.*—Another curious fact connected with their position is, that in a great number of situations there are found in the vicinity of hot springs, cold waters strongly impregnated with carbonic acid. In these cases it is observed, that the hot waters occupy the lowest point in the valley and river basin; and the cold springs possessing this peculiar composition, are placed at different elevations above them, either issuing from the bottom of the valley higher up the stream, from the declivities of its bounding mountains, or from the very summit or even reverse of the adjoining chains. Even in the present state of our knowledge, this circumstance is perhaps too general and too widely diffused in situations remote from each other, to admit of its being ascribed to mere local peculiarities. At present, however, I shall confine myself to a citation of the principal localities in which the phenomenon has been remarked.

The Karlsbad Sprudel, as is well known, emerges from the bottom of a narrow defile at the exit of the valley of the Tepel, into the plain of the River Eger. About a quarter of a mile further up the Tepel, near the pleasure house which has been called the Dorotheens Ave, and on the right bank of the stream, we find the cold acidulous spring which I have formerly noticed, as so remarkable for its large siliceous impregnation. This might rather be denominated a carbonic acid spring, than a true mineral water, for although the gas bubbles up with great violence through the water, the quantity of the latter is so small, that when the reservoir is once emptied, several days are necessary before it is replenished. South west from Karlsbad, in a sort of depression which separates the mountains bounding the left bank of the Tepel from the great mass of the Böhmerwaldgebirge, and ele-



vated about 1000 feet above it<sup>1</sup> are the cold purging waters of Marienbad, also highly charged with carbonic acid. Indeed, from every point of this plateau there issue springs possessing the same character, and carbonic acid is discharged in great quantities, uncombined with water, from the marshes between Marienbad and Einsiedel<sup>2</sup>.

In the duchy of Nassau the hot springs of Wiesbaden are placed at the southern base of the Taunus hills in the valley of the Rhine, near the mouth of the river Main (323 feet above the level of the sea), with a temperature of 158°. Farther up the valley of the Main (437 feet) we have the saline springs of Soden, with 88 cubic inches of carbonic acid<sup>3</sup>; and at a still higher level, (512 feet) and in the vicinity of the former, the saline springs of Cronberg, with 106.2 cubic inches of the gas. Immediately behind Wiesbaden on the margin of the plateau of the Taunus (897 feet) are the saline thermals of Schlangenbad, with a temperature of 87°, which contain only 7.42 of solid matters, according to the analysis of Kastner, and 6.4 cubic inches of carbonic acid.

On the opposite side of the Taunus in the valley of the Lahn, are the thermal waters of Ems (291 feet). Farther up the river are the acidulous-alkaline waters of Geilnau (337 feet), which, according to Bischof, contain 163.2 cubic inches of carbonic acid; of Fachingen (338 feet), with 134.8 of acid; and still farther up the Lahn, in the lateral valley of the Emsbach at the north eastern base of the Taunus, are the celebrated saline acidulous waters of Niederselters (445 feet), with 108.7 of carbonic acid. The same general character prevails in the springs which emerge from both declivities of the valley of Lahn, at different elevations above Ems. On the north, at the foot of the Westerwald, are the acidulous

<sup>1</sup> *V. Buch*, über Quellen Temperatur, in Poggendorff's Annalen, 1828; xii. 415.

<sup>2</sup> *Gilbert* (Annalen der Physik, vol. 74) estimates more than 60 of these springs within the bounds of the Abbey of Teipel alone, and says that almost every village possesses an acidulous water.

<sup>3</sup> *Stift*, Nassau, p. 529, &c.

springs of Montabaur (695 feet), with only 4.40 of solid matters, chiefly earthy salts, and 55.6 cubic inches of carbonic acid. To the south is the Salzborn at Braubach (423 feet), an alkaline spring with 58.4 cubic inches.

Not a single thermal water issues from the elevated plateau of the Taunus, interposed between Wiesbaden and Ems, but it furnishes an innumerable quantity of cold mineral waters, almost all of which contain a large dose of carbonic acid. Of these, the principal are the Weinbrunnen at Langenschwalbach (903 feet), with only 7.87 of solid matter, chiefly earthy carbonates, and 89.3 cubic inches of gas; the Stahlbrunnen at Schwalbach (909 feet), with 4.60 of solid matter, and 96.5 carbonic acid; the purging water of Rückershausen (206 feet), on the Aar, with 45.7 carbonic acid. Besides these, which have been specially analyzed, there are the mineral waters of Fischbach, (961 feet); of Ramschied, (1088 feet); of Springer, (934 feet); of Grebenroth, (1115 feet); of Schwaller, (779 feet); of Bannscheuer on the Mattenbach, (931 feet); and one between Holzhausen and Rettert, (851 feet); all of which are more or less impregnated with carbonic acid.

The hot springs of Bertrich are situate in the narrow valley of the Isbach near the Moselle, on the southern base of the group of the Eifel-gebirge; and those of Aachen and Burtscheid, occupy an analogous position at its northern extremity. In the intervening space, cold springs only are met with, most of which contain a large proportion of carbonic acid. Among these, I need only mention the acidulous springs of Spaa, with 74.4 cubic inches; of Malmedy, with 77.3; of Brohl, with 165.0; of Roisdorf, Tonnistein, Bru, La Sauveniere, and many others. I have formerly noticed (p. 34,) the analogy which these mountains present with the district round Marienbad, in uncombined carbonic acid being discharged in many places in great quantities from the soil.

In the valley of the Rhine are the thermals of Baden (616 feet) and Badenweiler. High up on the adjacent Schwarzwald mountains are the cold springs of Peters-

thal (1183 feet), with 68.7 cubic inches of carbonic acid; of Riepoldsau (1684 feet), with 140.8; of Griesbach (1487 feet), with 75.5; and of Antogast, with 68.7.

A few paces above the hot springs of Mont d'Or, there emerges a cold spring highly acidulated<sup>1</sup>, and which contains the salts usually found in these waters.

In the Alps, almost all the strictly acidulous waters are found in the Grisons at no great distance from the water shed of the chain, and in the superior prolongation of a valley, in which is situate a thermal water. The hot springs of Pfeffers (100° F.), in the valley of the Rhine, are at an elevation of 2128 feet. Farther up are the acidulous waters of Fideris at 2796 feet, with 92.7 cubic inches of carbonic acid; those of Bernardino, about 5500 feet<sup>2</sup>, with 60.1 cubic inches; and in the adjoining valley of the Inn, those of St Moritz (5571 feet), with 65.9; of Schulz, (3731 feet) with 101.0 cubic inches. The thermals of Vals (79° F.), are also at no great distance from the ridge of the Grisons, at an altitude of 2450 feet.

To the hot springs of Warmbrunn in Silesia, belong the acidulated chalybeates of Liebwertha, with 68.7 cubic inches of acid; and of Flinsberg, with 82.4.

Under the same category might perhaps also be included the numerous acidulous waters of the island of Gran Canaria, placed at different altitudes above the level of the sea; as, although there are no thermal waters in the island itself, we have traces of their existence in the group at a low level, in the hot water which springs from the bottom of the sea off the island of Palmas<sup>3</sup>.

<sup>1</sup> *Berzelius*, Karlsbad, &c. p. 72.

<sup>2</sup> The elevation of this mineral water has not been exactly determined. According to Rüsch, it is somewhat higher than that of St Moritz. Mount Bernardino has an altitude of 6584 feet, according to v. Welden, (Topographical Sketch of Mount Rosa, 1824; p. 88); and as the acidulous water of the same name is about an hour's distance from the summit of the mountain, it is probably about 1000 feet lower. It thus appears that these two acidulous springs are the highest of the European mineral waters.

<sup>3</sup> Von Buch hazards the conjecture, that many thermal waters may escape from the sides of these islands, and quite elude our ob-



## SECTION III.

## GEOGNOSEY OF MINERAL SPRINGS.

No ordinary difficulty attends the investigation of this department of the history of mineral waters, if we would endeavour to ascend from effects to their causes, the ultimate end of the labours of the naturalist. They are seen to issue from every rock-formation, whatever be its mineralogical composition, or the period of its formation. The true relations of a mineral water with the adjoining formations are, however, very imperfectly known; for, notwithstanding the attention which has been for ages devoted to their chemical composition and medicinal properties, and the numerous works which have been published upon these topics, in very few do we find even the bare indication of the rock from which they emerge to the earth's surface, much less of the geognostic structure of their environs. Recent geological researches, especially those of the Germans, who, from the abundance and variety of their mineral waters, possessed the widest field for observation, have begun, however, to disclose in some measure the regularity and beauty of arrangement which they present, and the correspondence of causes with effects so conspicuous in this as in all the departments of Nature, when the unwearied perseverance of the diligent student has forced her to remove the veil with which she envelopes her secret operations.

There are, however, two classes of mineral waters, whose geological relations are so obvious, that their true place has been always assignable without much difficulty. I allude to those hot-springs found to issue directly from, or in the vicinity of, active volcanoes: the source of their elevated temperature was evident: their im-

servation; and the more so, as the sea round them is so deep, that no fish can exist in their vicinity, because they find no ground for spawning.

pregnating solid and gaseous matters are such as are found in sublimations in the fissures of the adjoining volcanoes, or are discharged in immense volumes from their craters at every period of renewed activity. In many instances, too, as in the case of Pisciarelli, near Naples, they are seen to pass through phases, which differ in no degree, but in the magnitude of the scale upon which they are carried on, from those of volcanoes, their aqueous discharge ceasing altogether, and degenerating into the mere state of a solfatara,—itself destined, at no very distant period, to disappear in its turn. Brine-springs are the second class, whose parent formations, viz. great rock-salt deposits, could never for a moment be mistaken: their connection being so intimate, that, from the appearance of the former, we could always infer the proximity of the latter; and, from the largeness and simplicity of their foreign impregnation, we could conclude that no great distance intervened between these springs and their parent formation.

But with regard to other mineral waters, it is obvious that they are circumscribed between no such narrow limits. A spring may be originally derived from a formation very different from that from which it emerges to the surface of the earth; and the more modern this latter formation may be in the great series, or the farther it is removed from those which we regard as the most inferior of the crust of the globe, the more difficult will it be to assign the formation which ought to be considered as the parent of the spring. For instance, we may be certain that those mineral waters which issue from granite, can only have been derived from this rock, or from some point of the crust of the earth inferior to it. This cannot be affirmed of those which emerge from the primitive schists, transition-limestones and grey-wackes, coal-formation, mountain-limestone, and oolitic formations; with regard to which, we cannot be positive that they have not traversed all the series of formations interposed between these and the fundamental granite, or have even emerged from beneath this last.

If, however, amidst this diversity of formations, from

which mineral waters directly emerge, a certain uniformity can be discovered in the nature of the rocks found in their immediate vicinity, we shall perhaps be inclined to consider the former as of less importance in influencing the temperature and composition of some classes at least of these waters.

In the farther prosecution of this subject, it shall therefore be my endeavour to furnish the reader with a series of facts regarding the geognostic position of mineral waters, as far, at least, as the uncertainty of many observations, and my own imperfect acquaintance with it, may enable me to do so, as in this way he will be enabled more correctly to judge of the accuracy of the conclusions which may afterwards be deducible from a generalisation of the phenomena.

#### THERMAL SPRINGS.

In order to complete the chain of connection between the different classes of hot-springs, in reference to the rock formations with which they are connected, I shall, in the first place, give a rapid sketch of those which are connected with active volcanoes<sup>1</sup>, or their products.

Even so far back as the middle of last century, Ruttty thought himself justified in laying it down as a general rule, from the numerous observations which he had collected with the most diligent assiduity, "That wherever there are volcanoes or subterranean fires, there are hot-springs<sup>2</sup>."

Numerous hot-springs issue forth from the sides of, and at different distances from, the three active European volcanoes, Vesuvius, Stromboli, and Etna. In the environs of Naples, they emerge both directly from volcanic rocks and from the limestone mountains which stand in relation to them, either by actual superposition, or a greater or less proximity. The hot-spring of *Pisciarelli*, impregnated with sulphuretted hydrogen, flows

<sup>1</sup> By active volcanoes, I understand those of whose eruptions there are records in historical documents.

<sup>2</sup> Synopsis of Mineral Waters, p. 590.



from the slope of the Solfatara between Monte Nuovo and Pozzuoli, composed of a trachyte consisting of silex and alumina, with a little potash, iron, lime, and magnesia<sup>1</sup>. It is not unworthy of notice, that, in the peninsula of Italy, the central chain is a great ridge of limestone, at the western base only of which, on the shores of the Mediterranean, do we meet with thermal waters, as it is here that the products of volcanic activity have burst through the superincumbent rock. At the bottom of Etna is the hot sulphureous spring of *Santa Venera*. The island of *Lipari*, now known only for its hot-springs, although the ancients speak of its emitting fiercer fires than Stromboli, is composed of volcanic tuff, obsidian, and pumice. Besides the three great spiracles just mentioned, there are innumerable solfataras, most of which are accompanied by warm springs. The most remarkable of these are *Pozzuoli* and *Ischia*, whose volcanic eruptions now exist only in historical records. Under the geographical head, we have already seen the vast number of hot-springs which issue from this latter island. *Milo* is entirely volcanic, and it surpasses all the islands of the Archipelago in its display of hot-springs; and it can hardly be considered as the result of accident, that the islands which have been known to possess hot-springs, are precisely those in which recent researches have discovered the proximity of volcanic rocks. *Milo* is one of a series of islands, prolonged from the peninsula of Argolis (itself possessing a hot-spring near Mythone), composed of trachyte, trachytic conglomerate, trachytic tuff, and pumice, and including Santorini, Therasia, Aspronisi, Milo, Cimolis, Polino, Policandro, Poros<sup>2</sup>. We are not informed of the existence of hot-springs in the parallel range of Andros, Tine, Myconi, Zia, Syria, Paros, Naxos, Amorgos, and Stampalia, consisting entirely of primitive rocks, such as gneiss, mica-slate, and limestone. Near *Smyrna*, on the mainland of Asia, opposite the island of Mytilene, remarkable for its

<sup>1</sup> *Daubeny on Volcanoes*, p. 170. — <sup>2</sup> See the interesting account of the geognostic structure of the Grecian islands, in *Von Buch's Beschreibung der Canarischen Inseln*.

hot-springs, there is said to be found basalt and basaltic lava.

Perhaps there is no country in the world where volcanic eruptions have been so numerous, or have spread over so large a surface, as in *Iceland*. Subterranean fire has been exerted in every part of this extensive island, from Glamaca Isafiord on the north, to Eyafialla on the south, and Krabla on the east; and eruptions have been seen at a great distance in the sea, comprehending a space estimated by Sir G. Mackenzie at upwards of 60,000 square miles<sup>1</sup>. In fact, it would be more correct to consider this immense tract as one gigantic volcano, communicating with the external atmosphere by the six spiracles of Hecla, Krabla, Kattliagiau, Eyafialla, Eyrefa, and Shaptaa. Every part of the island emits steam, boiling siliceous mud, and sulphureous springs, with every degree of intensity and impregnation, up to the magnificent Geysers of Haukadal, Reikholt and Reikum, which emerge from the midst of a sea of congealed lava.<sup>2</sup>

In the island of *Java*, the order of arrangement observed in Italy is reversed. Here, as in that peninsula, hot-springs issue in great numbers from the craters of and sides of active volcanoes, and from limestone rocks; but the latter is evidently a recent deposit from marine animals on the great mass of volcanic rock of which the whole central part of the island is formed, and which contains the craters of no fewer than thirty-eight volcanoes, several of which are of immense magnitude, and in a state of incessant activity. The hot-springs of Cheribon, and sulphureous vapours in the neighbourhood<sup>3</sup>,

<sup>1</sup> *Mackenzie's Iceland*, p. 253.

<sup>2</sup> It is a curious fact, in connection with the immense volume of boiling water constantly discharged from the soil of Iceland, that the numerous eruptions of the different volcanoes (forty-two in number, between A. D. 900 and 1783), since the island has been inhabited, seem to have consisted chiefly of boiling mud, very few having emitted liquid lava, and that in comparatively small quantity. In 1755, the terrible eruption of Kattelagiau Jokul, which carried such destruction over the whole country, would seem, from the different accounts, to have consisted chiefly of torrents of hot water, very little lava having flowed.

<sup>3</sup> Can an analogy be here traced between Etna and Java? At

as well as the salt-springs on the island, flow out of this recent limestone. But it is exclusively from the volcanic products that those springs issue which contain the free muriatic, sulphurous, and sulphuric acids, and aluminous salts. It is from the limestone that emerge the different mud and petroleum springs of the island.

It will be seen on comparing the enumeration which I have given of the hot-springs in the great Indian Archipelago (p. 161.) with a catalogue of the active volcanoes of this part of the world, that these two classes of phenomena stand in the most intimate relation with each other. The thermal waters in *Kamtschatka*, we are informed by Krachenninikow, rise immediately from a formation of aluminous clay; but then we have at hand the volcanoes of *Awatcha*, *Tolbatchi*, and *Kamtschatka*.

*Amsterdam* Island, in the Indian Ocean, which gives out such a profusion of hot-springs, is a "volcanic crater."

*Pico*, the central island of the Azores, where they are very abundant, is "entirely composed of trachyte, pumice, and probably obsidian."

The Isle of *Bourbon* consists of an active and an extinct volcano: it is from the former, Mount Salazes, that there issue the hot sulphureous waters of this island.

In America, the well-known *Rio Vinagre* issues from the volcano of Purace, near Popayan. Hot sulphuretted hydrogen waters descend from the trachytic volcano of *Tolima*, which rises from the midst of the granitic rocks of Quindiu. The whole plain of the Malpays at *Jorullo* in Mexico is said to emit steam and hot water.

In the *West Indies*, the relations of the hot-springs bear considerable analogy with those of the Grecian Archipelago. As far as we yet know, they are found only in the inner or volcanic range of the Antilles, comprehending the islands of Grenada, St Vincent, St Lucia, Martinique, Dominica, Guadaloupe, Montserrat, Nevis,

the bottom of the former, we have seen the sulphuretted hydrogen springs of Jaci Reale. From the crater and different fumaroles higher up the mountain, sulphureous acid vapours alone are given out, or water slightly impregnated with muriatic acid.



St Christopher, and St Eustache, being entirely wanting in the outer range, consisting of Tobago, Barbadoes, Mariegalante, Grand Terre, Desirade, Antigua, Barbuda, &c. which constitute a series of low islands, composed of a new limestone, and a conglomerate, with a clay basis containing fragments of basalt, dolerite, and lava.

These localities will suffice to give an idea of this class of hot-springs. To enumerate them all in detail would, as formerly observed, amount to nothing less than an account of the distribution of active volcanoes on the earth's surface; for we have no instance of subterranean fires heaving up or bursting through the solid crust of the globe, without being accompanied with copious evolutions of steam and hot water, which are discharged, either from the crater itself, or from fissures and caverns in the surrounding country. Sometimes, indeed, these constitute the sole products of an eruption, either in a state approaching to purity, holding in chemical solution different acids and alkaline salts, or, in mechanical suspension, particles of clay, trachyte, lava, &c. in a state of minute division, constituting what has been called a volcanic mud or tuff. And it is observable, that these eruptions are much more destructive than those of liquid lava, as in South America and Iceland.

Let us now proceed to examine the geognostic relations of other thermal waters, which do not stand in connection with active volcanoes.

In Portugal, the hot-springs of *Caldas*, twelve leagues from Lisbon, and those of *Montegas*, at the foot of the Sierra de Estrella, both issue from granite, as also those of *Monchique*<sup>1</sup>.

Of the hot-springs on the northern declivity of the Pyrenees, those of

*Cambo*, at their Atlantic extremity, emerge from a blackish calcareous clay-slate, in very inclined strata, which rests on graphic granite, passing into the state of kaolin<sup>2</sup>.

<sup>1</sup> *Link*, Reise durch Portugal, pt. 2. p. 9. 82. 179.—<sup>2</sup> *Brongniart*, in Dict. Sc. Nat. t. 14. 1819. Article Eau, under Eaux Minerales.

*Bonnes.* From a transition clay-slate impregnated with calcareous matter, which rests on the granite seen a short distance to the south; where we find

*Eaux Chaudes*, about  $1\frac{1}{2}$  leagues farther up the valley of the Ossan, emerging directly from granite, which prolongs itself southwards to beyond the Pic du Midi. At no great distance from these two waters, are the greenstone masses of the Col du Larde, Aste, and Bedous.

*Cauterets.* From small-grained granite, with black mica and a little steatite, probably subordinate to the mica-schist formation, which forms the mountains of the Pic du Midi to the eastward. The central granite of the Lac d'Estem, is at a short distance to the south. These springs are situate near the junction of the mica-schist formation with a clay-slate of the transition series, containing beds of compact limestone.

*St Sauveur.* Placed in the basin of Luz, at the debouche of the valley of Bastan into that of Lavedan: in mica-schist of the Pic du Midi.

*Bareges.* Farther up the valley of Bastan, at the S. base of the Pic du Midi: from the calcareous clay-slate (calschiste), primitive or transition, resting immediately on the granite of Neouville.

*Bagneres de Bigorre.* At the exit of the Adour from the high Pyrenees: from compact grey limestone, with disseminated pyrites, alternating with transition clay-slate. Close by are the isolated fragments of granite of Pousac, la Bassere, and Lourerup: greenstone is found to the north of Pousac.

*Bagneres de Luchon.* From granite penetrating through and covered by a carboniferous clay-slate.

*Ussat*, near Tarascon. From limestone with caverns: granite of the Pic St Barthelemy, immediately to the east.

*Ax*, near the sources of the Arriege. From granite near its junction with the mica-schist formation of the valley of Ascou, and the transition rocks of Castellet.

*Oletta.* From granite of the sources of the Teta.

*St Paul de Fenouilhedes*, near Caudies, between Car-

cassonne and Perpignan ( $82^{\circ}$ ), from a cleft in a range of limestone hills. To the N. and S. of the cleft the strata are horizontal, and cover a series of schistous marls: on approaching the cleft, they sink down to the lowest level of the valley, and the subjacent marls disappear.

These interesting facts regarding the geognosy of the Pyrenean springs, for which we are chiefly indebted to the industry of the indefatigable Palassou<sup>1</sup>, shew us that not only the chief mass of the hot-springs of this chain of mountains are accumulated in its eastern half, where granite chiefly appears uncovered by the stratified rock, especially in Rousillon, between the valleys of the Tech and the Teta; but also that the others are only met with in defiles of the newer rocks, where the subjacent granite makes its appearance at the base of the declivity. It is even curious that the heat of these springs is proportioned to their varying proximities to the crystalline axis of the range. Those of Oletta in Rousillon are  $190^{\circ}$  F.; of Ax,  $181^{\circ}$ ; the hottest of Bagnères de Luchon, farther to the west,  $145^{\circ}$ ; Bagnères,  $122^{\circ}$ ; the thermals in the valley of Ossan, at the highest,  $100^{\circ}$ ; and, lastly, those of Cambo, not far from Bayonne, and farthest from the granitic nucleus, not more than  $70^{\circ}$ . We find in the Pyrenees sulphureous waters which are not thermal. Such are those of *Cadiac*, in the valley of the Aine: of *Bassere*, to the north of Bagnères de Bigorre; of *Sevignac*, at the bottom of the valley of Ossan; of *Dousoc*, in Chalosse; but it is remarkable that they all issue forth towards the foot of the mountains, and far from the primordial part of the chain. A solitary exception to this rule is formed by the thermal waters of

*Dax*, in the department of the Landes, which possess the high temperature of  $140^{\circ}$ . They issue from compact limestone; but we are informed that at no great distance are to be found trap-rocks<sup>2</sup>. It is doubtful, however, if they are attachable to the Pyrenean system, as they contain no sulphuretted hydrogen, consisting

<sup>1</sup> Mémoires pour servir a l'Hist. Nat. des Pyrenees, 1815, p. 435.

<sup>2</sup> Brongniart, Eaux minerales.



of nearly pure water, with a little of the muriate of magnesia and sulphate of soda.

It has been observed by Professor Daubeny<sup>1</sup>, that the thermal waters of *Dax*, of *Oleron* near Pau, of *Capvern* near Bagnères, of *Encausse*, near Gaudens, which are placed at the greatest distance from the axis of the chain, are exactly on the boundary line between the rocks which have been uplifted and those which have subsequently been deposited, according to M. de Beaumont's theory on the mode of formation of mountain chains.

*Campagne*, in the department de l'Aude (79°), issue from a calcareous and aluminous soil? It contains carbonic acid and sulphate of magnesia.

*Balaruc*, near Montpellier. From secondary limestone: contains carbonic acid.

*Cranzac*, *Senzac*, &c. From the coal-formation: contain carbonic acid.

*Bagnols*. From compact limestone (alpine or Jura), not far from the granitic formation.

We now come to the thermal waters of the central departments of France, the most general idea of which is, that they consist of a series of masses of basalt, trachyte, and their tuffs, which constitute those innumerable *buttes* and extinct craters for which this district is so remarkable, and which have of late furnished such important facts to the geologist. These deposits repose on granite, which is seen here and there at the bottom of the valleys, and more extensively on the western outskirts of the province of Auvergne.

*Vic* (en Carlades), and the others which emerge from the foot of the Cantal. Immediately from granite. According to Cordier, they consist of nearly pure water, at the boiling temperature.

*Vals*, in the department of the Ardeche (131° Brongniart). From granite, the felspar in a state of decomposition. The rock from which they issue is covered with a saline or rather alkaline efflorescence. All the

<sup>1</sup> On Thermal Springs, and their connection with Volcanoes, in Edin. New Phil. Journ. No. 23, Jan. 1832, p. 53.

adjoining summits consist of the extinct craters and lavas, extending over the whole of the Vivarais, which in many places are ruptured and heaped together in irregular masses, especially in the bottom of the valleys, exposing the fundamental rocks, which are chiefly primitive. Coal formation is seen at Prades. Mountain limestone also makes its appearance, extending as far as the valley of the Rhone.

*Chaudes Aigues.* From gneiss, mica-shist and clay-slate. These rocks belong to a high granitic chain, known by the name of Margeride, which ranges on the north and west of the volcanic group of the Cantal, and south of that of Aubrac. The lavas which have issued from the craters of Cantal and Aubrac cover the whole of the surrounding country, and have extended to the foot of the Margeride.

*Mont d'Or*, in the valley of the Dordogne, at the foot of the volcano of the same name.—Issues from a fissure in trachytic porphyry. The chain of Mont d'Or consists of two classes of rocks. Superiorly we find basalt, with trap-tuff and breccia. Beneath this formation is trachytic porphyry, which is seen in the sections formed by the valleys. In the vicinity of the baths, this trachyte-porphry passes into pitchstone and hornstone porphyry, traversed by numerous dikes of porous basalt connected with that of the different summits. Below all these rocks is found the granite, which appears at the surface towards the western extremity of the valley of Dordogne, near the village of Bourboule, about four or five miles below the springs<sup>1</sup>.

*St Nectaire*, in a deep fissure in the mountains on the left bank of the Couze, at the foot of the gigantic mass of Mont d'Or. They flow directly from gneiss in a state of decomposition. The surrounding heights are covered with fragments of basalt, which extend pretty far to the eastward. The valley from which the springs issue, opens into a sort of basin, closed to the eastward by the lavas which have issued from the volcano of

<sup>1</sup> *Daubeny* on the Volcanoes of Auvergne, in the Ed. Phil. Journ.

**Chambon.** Towards the west, near Sailhens, the Couze precipitates itself in a beautiful waterfall over a steep basaltic precipice. Farther down, near Verrieres, the basin becomes narrower, and the river flows for more than four miles in a narrow ravine, the walls of which are granite, and the summits covered with ancient lavas; and in the bottom is found modern lava, which has issued from Chambon, and has filled the whole of the bottom of this narrow ravine. To the south of these springs is a vast granitic plateau, which bounds on the west the whole of the Limagne.

Many hot-springs issue from the vicinity of the different lava streams which have flowed from the craters surrounding the Puy de Dome in all directions. They can be traced along the course of the different valleys as far as the Plain of the Limagne. Of these, the principal are,

*St Allyre*, in a suburb of the town of Clermont, which issue from a *butte* composed of the debris of aphanite, and other allied rocks. Deposits calcareous incrustations in great abundance.

*St Mart* and *Chatel-Guyon*, near Clermont. From below the volcanic formations; perhaps from the granite<sup>1</sup>.

*Vichy*, on the banks of the Allier. Flow immediately from a calc-tuff (Rocher des Celestins), evidently a recent deposit from the springs themselves. Below this is a bed of fresh-water limestone, which is succeeded by granite. This limestone is covered by the different lavas and volcanic tuffs of the Limagne<sup>2</sup>.

*Neris*. From the coal-formation, surrounded by granitic rocks.

<sup>1</sup> *Bischof* (Vulk. Mineralq. p. 219.) enumerates the following springs, all of which issue from beneath the steep lava precipices in which the different streams of modern lava generally terminate, viz. *St Vincent*, *Sayat*, *Nohannent*, *Fontmore*, *Royat*, *Oradou*, and *Mas-sayes*.

<sup>2</sup> This is the account given by *Berthier* and *Pavis* in their description of the thermals of *Vichy* (*Annales des Mines*, v. 401.). *Brongniart's* statement is somewhat different (*Dict. des Sc. Nat.*): he asserts them to issue from the alpine limestone and coal formation, associated with a porphyritic breccia.



*Bourbon l'Archambault.* From a transition schist with alpine limestone.

*Bourbon-Lancy.* From the limits of the granite, and the alpine limestone and coal formation.

From this, it is seen, that here, no less than in the Pyrenees, the hot-springs can be primarily referred to the fundamental granite, although their connection with the trachytic and basaltic masses of the country is much more intimate than that of the Pyrenean springs with the different trap masses of that range, which might be considered as holding the place of the trachytes of Auvergne, in relation to the granite. Salts of soda are the chief solid ingredients in both districts; but in the one, the predominant gas is sulphuretted hydrogen; in the other, it is carbonic acid. The greenstone buttes of the Pyrenees are chiefly scattered in the western part of the chain, and at the very base of its central portion, and are quite wanting in the eastern division, all situations farthest removed from the granitic nucleus where the hot-springs are most abundant; whereas in central France, they burst forth more especially from the granite, near its junction with the more modern igneous rocks, and from the midst of these last themselves; but they are not found in the widely extended granitic plateau of the Limagne, western Auvergne, &c. at a distance from the modern volcanic rocks.

In the north-east and north of France, the thermals of

*Luxueil* issue from beneath the arkose (red sandstone) of the Vosges, which rests immediately on granite.

*Bourbonne les Bains.* From compact Jura limestone.

In the vicinity of the Pennine (Western) Alps, we find:

*Aix* (Department of the Mouths of the Rhone), which issues from a formation of compact Jura limestone. In the vicinity of the baths are some remarkable dislocations of the fresh water formations of the country<sup>1</sup>.

*Greoulx*; from Jura limestone in highly inclined strata.

<sup>1</sup> Murchison and Lyell in Edin. New Phil. Journ., No. xxi.

*Aix* in Savoy. From a white compact shell limestone at the foot of the chain which skirts the lake of Bourget.

*St Gervais* in the valley of the Arva, at the north base of Mont Blanc. From a foliated felspathic (*petrosilex*, Brongniart) rock.

*St Didier*, near Courmayeur, at the southern base of the same mountain. From a limestone alternating with a mica-slate.

*St Vincent*, on the road from Jaree to Aosta. From talcose mica-schist.

*Viray*, in the valley of the Stura in Piedmont. From a primitive limestone resting on talcose mica-schist.

*Acqui* in Piedmont. From the same formation.

*Leuk*. From the Gemmi in the Valais, a mountain composed of calcariferous clay-slate and alpine limestone.

According to the observations of Mr Bakewell, the numerous thermal waters in Dauphiny, Savoy, Valais, and Upper Piedmont (almost all of which have been discovered since Saussure's Travels<sup>1</sup>), lie partly in the primitive rocks of the central chain itself, but in still greater numbers at their margin, on the boundary of the primitive and secondary formations, where the strata give indications of having been torn by violent rents. From these facts, and also from the remarkable circumstance that they are few and inconsiderable in the high chain of the Bernese Oberland, formed of an immense cover of secondary rocks, it is probable that the seat of these springs must be sought for in the primitive rocks themselves. All along the southern declivity of the Alps, a continued chain of hot springs emerges from the line of junction of the primitive with the newer rocks, which can be traced from the foot of Mont Blanc and the great St Bernard, to the volcanic products of the Euganean hills, in which line are found the thermals of *St Didier*, *Acqui*, *Pelegriano*, *Bormio*, *Masimo*, *Caldiero*, *Abano*, *Battaglia*, *Monte Ortone*.

<sup>1</sup> Philosophical Magazine, January 1828, p. 14. Those in the valley of Bagnes, filled up in 1545; in Chamouni, discovered in 1821; *St Gervais*, in 1806; *Brida*, in the Tarentaise, formerly filled up, and again discovered in 1819; some at *Grenoble*, discovered in 1820.

*Bobbio*, in the valley of the Trebia near Genoa. From an argillaceous limestone in very contorted strata.

*Baden* in Switzerland (Canton of Argovie). From below the Jura limestone, at the bottom of the valley of the Limmat.

*Schinznach*, not far from the former (Canton Aargau), issues directly from a marly sandstone, very probably resting on the granite of the Black Forest, which appears uncovered in different parts about five miles from the springs.

*Gastein* in Salzburg. From granite and gneiss.

*Baden* near Vienna. Issue immediately from calc-tuff.

In the Alps themselves no true basalt or porphyry rocks exist<sup>1</sup> to connect with their warm springs; but these mountains probably belong to those primeval convulsions in which the gneiss and mica-schist strata experienced the uplifting energy of the subjacent granite, which itself appears in many situations at the surface, and forms the constituent rock of the colossal Mont Blanc. Basaltic and other congenerous rocks only appear at the base of the chain, forming a series of buttes and eminences, in the hollow in which is situate the Rhine and the Lake of Constance, bounded on the south by the primitive Alpine ranges, on the west by the secondary rocks of Bern and the Jura, and on the north by the primitive rocks of Suabia. No thermal waters issue forth in this hollow, although there are many acidulated springs of a peculiar composition, whose relations to these igneous masses will come to be afterwards considered. It is true that the basaltic clinkstone and trachytic formation in the vicinity of Kaiserstuhl approaches within ten or fifteen miles of the hot springs of Baden<sup>2</sup>. We have formerly seen that not a single

<sup>1</sup> *Saussure*, in his *Voyages aux Alpes*, i. 144, affirms, that, after having examined with the most scrupulous attention all the chain of the Alps from Grenoble to Innsbruck, he had not discovered in the rocks the slightest trace of subterranean fire. Farther to the east, in the vicinity of Grätz, in the Tyrol, Von Buch has described the existence of a trap formation; (Üb. einige Berge der Trapp formation bei Grätz, Berlin 1820.)

<sup>2</sup> *Keferstein*, *Deutschland geognost-geolog. dargestellt*, i. 67.



thermal water is found in the space extending from the Böhmerwaldgebirge to the Black Forest, comprising the kingdom of Bavaria, and the south-east of Suabia; neither does this tract afford any indications of its strata having been violently acted on by a force posterior to the epoch of their consolidation, no basaltic or clinkstone buttes appear above its surface, nor is the granite seen at the bottom of any of its valleys <sup>1</sup>.

Again, however, on approaching the primitive range of the Schwarzwald, we meet with warm springs: thus the *Wildbad* in Wurtemberg rises from primitive rocks. At some little distance to the south is the gneiss of the Kniebis, the highest mountain of the range. Basalt is not found nearer than Dettingen and Urach, about forty miles distant from the springs.

Almost all the springs just enumerated contain but a small quantity of solid matter, and are remarkably contrasted with those of the Pyrenees and Auvergne in their nearly total destitution of the salts of soda.

Of the numerous hot springs in the range of the Carpathians and in the Transylvanian mountains<sup>2</sup>,—those of *Eisenbach*, in the valley of the same name, near Schemnitz, issue directly from a grey compact limestone. The mountains which rise above the baths on both sides of the valley are composed of trachytic porphyry. Immediately behind the town is an arenaceous quartzose rock, which is succeeded farther up the valley to the eastward by porphyritic greenstone, syenite, and, lastly, granite and mica-schist, which forms the fundamental formation of the district. The nearest point to the westward where granite and mica-schist occurs, is on the opposite bank of the Gran, in the high mountains in the vicinity of Hochwiesen, about three and a half leagues from the springs. The intermediate space is occupied by trachytic porphyry, and their conglomerates. Here and there basaltic masses rise in the lower parts of the valleys; the nearest of these to the springs is the Calvarienberg, in the plain of the town of Schemnitz, about two

<sup>1</sup> V. *Hoff*, Geschichte der Veränderungen der Erdoberfläche, ii. 335.—<sup>2</sup> *Beudant*, Voyage en Hongrie, i. 286, 322; ii. 32, 326, 393.

leagues from the springs. Two basaltic masses are also found on the banks of the Gran, near Magospart.

*Glasshütte*, about three miles to the north-east of the preceding (129° F.). The springs which supply the baths emerge from a hill of calc-tuff, apparently formed by their own depositions, enclosing the debris of plants and the shells of land mollusca; but there are several other springs in the valley (100°), which issue from a limestone analogous to that of Eisenbach, which forms a hill of considerable altitude (2300 feet); immediately to the south of which is porphyritic greenstone with syenite, and the primitive mass (granite and mica-schist) of Mont Szalas. The Calvarienberg is about six miles distant to the south; and about the same distance to the north are two basaltic masses, on the banks of the Gran near St Kereszt. In the lower part of the valley of Glasshütte are trachytes and porphyries analogous to Eisenbach, with the addition of pearlstone near its embouchure in the Gran.

*Mehadia* in the Bannat. Emerge from limestone which rises into mountains of considerable elevation between the springs and the valley of Cserna: it is prolonged as far as the Danube and to the west as far as Moldavia: it contains large caverns at Veteroni, Kolumboes, &c., and constitutes the deep ravine through which the Danube escapes from the great Hungarian basin into Wallachia. On the west declivity of the valley of Mehadia, Esmarck indicates the presence of mica-schist as extending as far as Orsova.

*Budos*, on the frontiers of Transylvania, celebrated for its discharge of hot sulphureous vapours, and at whose base are many mineral waters, is a great trachytic mass; in many places in a state of decomposition from the action of the gaseous exhalations.

The only hot springs met with in the vast plains of Hungary are:

*Buda*, which issue from beneath a hill on the right bank of the Danube, composed of an argillaceous grey limestone, intermixed with particles of mica and grains of quartz, and which contains a few fossil bivalve

shells. In the vicinity of the baths the strata are deranged from their horizontal position, and inclined in opposite directions in the mantle-shaped stratification. The whole surrounding country consists of alluvial deposits and loose sands and sandstones, out of which there rise different eminences of limestone (mountain, magnesian, and *grossier*). The trachytic formation (conglomerate) is found at the distance of four and a half leagues in the vicinity of St Andre, on the banks of the Danube. Basalt is not nearer than Lake Balaton, more than twenty-five leagues distant.

*Erlau.* From a compact grey limestone. Calc-tuff resembling that deposited by springs occurs in different points round the town. The hills in the environs consist entirely of pumice conglomerate, covered in several places by fine quartzose sands, containing shells and rolled masses of quartz and limestone. About six miles farther to the west is the trachytic mass of Mont Matra, which rises abruptly to the height of 2500 feet above the alluvial plains stretched at its base; and the porphyritic greenstone of Parad. The granite of the county of Gömor is more than fifteen leagues distant.

With this terminates what we know of the geognostic relations of what may be called the southern parallel of the European hot springs; I shall, therefore, now proceed to a similar examination of the northern parallel, the different members of which are situate in the Eifel, Taunus, Erz, and Riesengebirge. And, first, of those of—

*St Amand*, isolated to a considerable distance from the rest on the banks of the Scheldt, in the plains of Belgium, not far from Valenciennes; issue probably from below the chalk which covers the coal formation.

*Aachen* and *Burtscheid*. Rise from the junction of a blackish compact limestone (mountain) with micaceous greywacke slate. They are distant more than twenty-four miles from the basalts and extinguished volcanoes of the Eifel mountains near Bonn<sup>1</sup>.

*Bertrich*. From greywacke slate. Immediately at the baths, the sides of the Valley of Isbach are formed by

<sup>1</sup> *Hausmann* in Nöggerath's Rheinland Westphalen, i. 281.



lofty basaltic columns, prolonged for some distance on the right side of the stream. This basalt in some places exhibits the spheroidal structure, and in others is replaced by a basaltic conglomerate. On the adjoining heights are;—on the north the extinct crater of the Falkenlei, the steep precipices of which are formed by masses of porous slags of a brownish, red, bluish, black and yellow colours, which pass into a grey-coloured basalt with olivine, and by degrees into perfectly characterized black compact basalt; there occasionally occur among the slags fragments of greywacke slate, bearing evident marks of having been changed by heat:—on the south extremity of the plateau, the crater of the Facher, surrounded with masses and loose blocks of slags, which terminate towards the valley, like those of Falkenlei, in steep precipices more than twenty feet high<sup>1</sup>.

*Ems.* Rise from a solid greywacke slate with a silicious cement, intermixed with numerous foliæ of mica, which forms the fundamental rock of the whole surrounding country on both banks of the Lahn. Between the layers of rock are numerous beds of alum-slate; and it is traversed in different directions by veins of quartz with traces of galena. Behind the baths rises a steep rock, consisting of a newer slate, impregnated with oxide of iron, the upper part of which is calcareous, and contains two beds consisting entirely of petrifications (pectinites and terebratulites). A short distance to the north-east, in the Arzbach, there rise from the midst of the greywacke, here covered by a quartzose rock, two hills, consisting of grey-coloured feldspathic rock, with crystals of glassy felspar and aciculæ of hornblende (trachyte), containing grains of magnetic iron. These hills are placed at the north-west declivity of a sort of plateau which extends from Welschneudorf to the vicinity of Ems; on the southern margin of the plateau, near Kimmenau, is columnar basalt, passing into clinkstone, with crystals of augite and glassy felspar (no olivine)<sup>2</sup>.

<sup>1</sup> V. Dechen in Nöggerath's Rheinland Westphalen, iii. 113.—

<sup>2</sup> Stiff's Nassau, p. 427, 429, 375, 438, 404, 364.

*Wiesbaden.* Rises from the alluvial deposits of the banks of the Rhine and Lahn, close to their junction with the clay-slate, which is the constituent rock of the whole range of the Taunus, and is succeeded to the north by the greywacke and greywacke-slate of the plateau between the Main and the Lahn. The Geisberg, immediately behind Wiesbaden, consists of talcose slate, covered by beds of hornstone, passing by degrees into the sandy clay of the plain<sup>1</sup>. This hornstone is not separated from the slate by a distinct line of demarcation, but at the point of junction they mutually penetrate each other. The talcose slate consists of a slaty compound of quartz and talc, chlorite or mica; at Himmelrohr felspar is superadded to these ingredients. Higher up on the ridge of the Taunus pure quartz masses occur resting on the above slaty rocks. North-north-east of Wiesbaden a series of five basaltic masses range from Sonnerberg by Rambach and Naurod to the Kellerskopf, one of the summits of the Taunus. A fresh water formation extends from Wiesbaden to the vicinity of Fort Montebello (with Bulimus).

*Schlangenbad.* From the talcose and chloritic slate of the Taunus. In the vicinity of the road to Wambach it is much impregnated with oxide of iron, and traversed by numerous quartz veins,

*Soden* (73° F.). In a plain at the line of junction of the talcose slate of the Taunus with the alluvial deposits of the Main, which are here principally boulders of quartz united together by a cement of clay. Some distance to the south-east, at Eschborn, is a fresh-water limestone.

*Karlsbad.* On account of the remarkable peculiarities in the position of these celebrated waters, it will not be uninteresting to enter, with regard to them, into a little more minute details. The hot water issues forth from an immense number of orifices, but of these the seven following are at present used for medicinal purposes:—the *Sprudel* or *Alte Sprudel*; the *Hygeias* spring or *Neue*

<sup>1</sup> The inferior beds of the whole of the alluvial deposits of the Main consist of hornstone, calcareous sand, and clay,

*Sprudel* ; the *Muhlbrunn* ; the *Neue Brunn* ; the *Bernhards Brunn* ; the *Theresien Brunn* ; and the *Schloss Brunn* : of these the five first are situate close to the bed of the Tepel, or very few feet above it ; the two last a little higher up the declivity of the Schlossberg, on the left bank of the river. The water of the first set of springs emerges from different artificial openings which have been made in a calc-tuff deposit, formed by the water itself, through which it is propelled with considerable violence : this tuff in some situations forms a sinter of a very crystalline and compact texture. In the years 1713 and 1727 this calcareous mass was ruptured by the force of the enclosed water, which was thus discharged immediately into the Tepel. In order to ascertain the cause of this phenomenon, the exterior layer of the limestone was penetrated, immediately upon which the hot water burst forth with great violence, and was found to be contained in several hollows in another crust of tuff : this penetrated, the water issued forth with still greater violence ; and a third crust was found, which, when also penetrated, disclosed a great cauldron of boiling water, to which the name of the *Sprudel Kettle* has been given, and which disengaged aqueous vapour and gas with such violence that all further investigation was precluded. The aggregate thickness of the three tufaceous vaults was estimated at from one to two ells, consisting of a whitish and brownish yellow calc-sinter ; but they are not placed concentric to each other, their intervals being separated by irregular partitions, forming as it were separate reservoirs. The surface of the water in the Kettle was about three or four ells below the external surface of the outer calcareous crust. It was attempted to be fathomed by introducing long rods for the distance of more than thirty fathoms, but nothing was found ; the direction from which the water flowed seemed to be in that of the Hirschenstein, so that it is evident that the greater part of the town of Karlsbad is built on the crust of this vast boiling reservoir. Accordingly most of the cellars of the houses are filled with carbonic acid gas, which issues through fissures in



the rock, and it would only be necessary to penetrate this to a very short distance to obtain a spring of hot water. Numerous bubbles of gas are seen also to issue from the bed of the Tepel in the calm pools of water.

The other two springs issue from granite, which constitutes the great mass of the hills on both sides of the Tepel. Its most common variety is small-grained, with a large predominance of felspar, which often forms a basis in which are imbedded irregular grains of quartz and small plates of mica. The felspar is generally opaque and reddish-white, and is sometimes collected into prismatic crystals more than two inches long, giving to the rock a porphyritic character. The mica is usually dark grey, occasionally red when the foliæ are of large size. The quartz is seldom very abundant, and has its usual glassy appearance. Occasionally the grain becomes much larger, from the more regular crystallization of the felspar; the mica then forms larger laminae, and the quartz is nearly excluded. The fine-grained variety in the vicinity of the Schloss Brunn is traversed by many veins of hornstone, and contains larger beds of the same substance, associated with quartziferous iron-pyrites, also beds of a compact and granular limestone. This granite is frequently traversed by fissures in different directions, giving it an irregular columnar and tabular structure, but no regular stratification. Occasionally there are veins of felspar of considerable size. From the great abundance of the felspar, it is generally very easily decomposed, giving to the weathered surface a rough and coarse aspect.

At the northern base of this granitic mass, where it faces the valley of the Eger, is found a sandstone with vegetable impressions, in which have even been found whole trunks of trees and particles of coaly matter, which probably forms the inferior beds of the great brown coal deposit so abundant on the north back of the Eger, extending from Dallwitz, by Hohndorff and Fischern, as far as the town of Eger, many parts of which are in a state of combustion, forming the pseudo-volcanic deposits which formerly figured so much in

some theories on the origin of the caloric of the Karlsbad waters. Basalt is found resting on the granite near Fischern, about two miles from Karlsbad; and at Grassberg, near Engelhaus, about three miles to the east of the town, is the clinkstone mass of the Schlossberg.

*Teplitz.* Emerge at the south-east base of the stanniferous porphyry formation of Altenberg and Zinnwald. Most of the eminences which rise immediately to the east and south of the town are formed of a rock which is a granular compound of quartz, felspar, and mica, occasionally porphyritic from the more regular crystallization of the felspar. The mica often disappears altogether, and the quartz diminishes much in quantity. Reuss<sup>1</sup> says that true clinkstone occurs at the Schlossberg, Kirschberg, &c. The rock often assumes the columnar form, or decomposes into large cubic masses, which form steep cliffs, with a talus of debris at their base, consisting chiefly of a reddish-grey gravel, arising from the decomposition of the felspar. This debris is most abundant at the foot of those cliffs in whose composition felspar is by far the most predominant ingredient. To the west of Teplitz is an extensive coal deposit. The clinkstone mass of the Donnersberg, the highest of the Bohemian Mittelgebirge, is twelve miles distant to the south; but the principal mass of the group is not more than five miles off. The intervening space is covered by Jura limestone.

*Wolkenstein* and *Wiesenbad* are situate immediately at the base of basaltic masses, traversed by a prodigious number of veins of wacke<sup>2</sup>; they issue directly from gneiss.

*Warmbrunn.* From fissures in small grained granite; the central rock of the Riesengebirge. Basalt occurs about eight miles distant in the Schnee-grube, near the sources of the Elbe<sup>3</sup>; at the Kohlenberg near Querbach, at Wickenstein near Neusorge, at Steinrücken

<sup>1</sup> Mineralog. Geographie v. Böhmen, 1793, p. 1.—<sup>2</sup> *Werner's Theory of Veins*, Eng. Trans. 1809, p. 77.—<sup>3</sup> *Singer* in *Karsten's Archiv. f. Bergbau, &c.* iii. 86.

between Börngrütz and Neukemnitz, and near Langwasser<sup>1</sup>.

*Landeck.* From gneiss. Close by is basalt at Überschaar and Wrinklerberg, near Rom.

In the European islands are those of—

*Buxton*, in the north-west angle of Derbyshire in England. In a valley on the *west* edge of the great limestone ridge, which extends through the county of Derby from Castleton southwards, constituting what has been called the Peak Forest. The surface of this district is occupied by the outgoing of four strata of limestone and three beds of amygdaloid (toadstone), interposed between the limestone strata. Above the upper stratum of limestone is one of a coarse sandstone or millstone grit, considered by many as the inferior bed of the coal formation, which occupies the whole country to the east and north of this district. Buxton is immediately to the south of the outgoing of the lowest stratum of limestone. The limestone is of a whitish or yellowish colour, is full of encrinites, madrepores, and other organic remains, and contains many large caverns, for which this district is so remarkable. The direction of the strata is generally north and south, with a dip to the east under the coal formation. Granite is found at Mount Sorrel, to the north of Leicester, at the distance of about fifty miles, associated with schistose and trap rocks.

*Matlock.* On the declivity of a hill of limestone on the banks of the Derwent. It is on the *eastern* edge of the great mountain-limestone formation of the country.

There is a great fault in the valley of the Derwent at Matlock produced by the limestone and toadstone strata, the upper bed of limestone on the western side of the valley being brought down below the second bed on the east, and the first bed of toadstone on the one side being parallel to the second bed on the other<sup>2</sup>. According to Mr Farey<sup>3</sup>, the same fault can be traced into Staffordshire and north as far as Buxton, where it passes imme-

<sup>1</sup> V. *Raumer*, Geognost. Darstellung des Nieder Schlesiens, Glatz, Oberlausitz, &c. 1819, p. 131.—<sup>2</sup> *Whitchurst's* Theory of the Earth, plate ii.—<sup>3</sup> *Farey's* Derbyshire, v. i.



diately through the spot from which the thermal waters issue. It even stretches north-west from Buxton to *North Bradwell*, where there is a spring with a temperature of  $58^{\circ}$ , and terminates at *Litton* near Tideswell (about a mile from Stoney Middleton), where there is another spring constantly at  $64^{\circ}$ . We are also informed by Professor Daubeny<sup>1</sup>, that the only other springs in Derbyshire which possess a temperature above the mean of the climate are one at *Stoke Park*, about a mile from Stoney Middleton, and one in the town of *Bakewell*, which is encircled by a fault which sweeps round from Beely, south-west of Bakewell, to Baslow, north-west of the same place.

*Bath.* In a deep valley in lias limestone; issues from a compact blackish sublamellar limestone. It is nearly on the margin of the lias and oolite formations, the latter being found in the hills immediately above the valley, and part of the city is built on a variety of it called Roestone.

*Bristol.* Emerges from the bottom of St Vincent's Rock, which is composed of a compact limestone, traversed by numerous veins of calcareous spar, containing quartz crystals, which is extensively quarried as a building stone. The defile from which the hot springs in the vicinity of St Vincent's Rocks on the banks of the Avon issue is remarkable for the dislocation of the limestone strata<sup>2</sup>. They experience a great fault to the amount of 150 fathoms. The first limestone bed of the series occupies the face of a steep precipice, the middle of which is indented by a deep chasm. At the foot of the chasm bursts out the hot spring. Immediately beyond the chasm is an old quarry. From the hot wells to the quarry the strata rise to the north-west at an angle gradually decreasing from  $40^{\circ}$  to  $15^{\circ}$ ; immediately beyond it the less inclined strata abut against others thrown up at an angle of  $70^{\circ}$ , and exhibiting a remarkable curvature in the upper part. Bristol is placed at the western border of the lias formation, at its junction with the new

<sup>1</sup> Edinburgh New Philosophical Journal, Jan. 1832.—<sup>2</sup> *Buckland* and *Conybeare* in Geolog. Trans. Series ii. v. i. pt. ii. 1824, p. 241.

red sandstone, remarkable for its gypsum deposits, and the lower part of the town is built on it.

To the north of these two last hot springs, rocks of an amygdaloidal basalt are continued southwards in the direction of the springs, from Worford Bridge in Gloucestershire<sup>1</sup>, connected with the mountain limestone of that district, as in Derbyshire.

The thermal water of *Taafe* in Wales, is near the point where the beds of shale, millstone, grit and mountain limestone, previously nearly horizontal, begin to rise at a considerable angle to the south.

*Mallow*, in Ireland, from a hill of limestone.

*Sciacca*. From the blue clay formation which occupies a great space in the south-west part of Sicily, containing crystals of sulphate of lime, sulphate of strontian, sulphur, iron pyrites, and alum, and in which is the mud volcano of Macaluba. Higher up Mount Calogero than the point from which the springs issue, we lose the clay and come upon a white saccharoid limestone.

*Bonarbashy*, in the plains of Troas. Bursts from crevices in a stratum of puddingstone covered by limestone.

*Maschuka*, in the Caucasus. At the foot of Mont Maschuka, 1400 feet high. South declivity of the hill to height of 400 feet, is a great mass of fibrous calc-sinter, from which the springs issue. Mont Maschuka is composed of limestone, rising out of the midst of an alluvial district, and not broken through by the trachyte, which constitutes most of the eminences in the plain. Its strata are inclined at a high angle, and on the summit are nearly horizontal. On the south-east side is a deep fault.

*Eisenberg*. Issue directly from trachyte in a kettle-shaped cavity in the trachytic mass of the same name. They deposit copiously calc-sinter, coloured with oxide of iron.

*Kumgara*. Issue from indurated slate-clay at the north base of the trachyte mass of the Kumgara.

*Katherinen*, *Pauls*, and *Petersquellen*, all issue from sandstone, sandstone blocks, and fragments on the north

<sup>1</sup> Rees' Cyclopaedia, Art. Temperature of Springs.

declivity of the sandstone chain which extends from the river Terek to the chain of the Caucasus. On approaching the mountains, we meet first with a conglomerate composed of fragments of limestone and trachyte, then with a limestone (Jura) in highly inclined strata, resting on older limestones and slates, which themselves repose on the trachyte which constitutes the snowy summits 12,000 or 15,000 feet high.

From their high temperature, these Caucasian springs hold but little gaseous matter in solution; but they all disengage from their basin copious streams of carbonic acid and azote, so as to appear as if boiling.

Granite is the prevailing rock of the chain which forms the southern prolongation of Mont Liban into the Hedjaz of Arabia, which yields many thermal springs. Here and there are beds of greenstone.

The thermal and acidulous springs of the *Valley of Mexico* issue from porphyry.

Near *Havana* in the island of Cuba, sulphureous springs emerge from serpentine abounding in diallage and alternating with transition syenites<sup>1</sup>.

In South America, primitive rocks yield those springs with which we are best acquainted, when they do not issue from modern volcanic rocks, especially granite, when not very elevated above the sea, or mica-slate from its junction with the superincumbent trachyte of the thickly scattered volcanic cones of this quarter of the globe.

All the hot mineral waters of the Cordilleras of Venezuela emerge from the primitive rocks grouped round the granitic centre of Mariara, a branch of the Sierra Nevada de Merida. Of these—

*Trincheras*, near Portocabello. Issues from a large grained granite, stratified, and superposed to gneiss.

*Onoto*. From gneiss.

*Mariara*. From gneiss.

*Bergantin*, south-east of New Barcelona. From quartz-

<sup>1</sup> *Humboldt*, *Gisement des Roches*, p. 193.



ose sandstone resting on compact white (Jura) limestone with beds of black hornstone.

*San Juan.* From compact white limestone with conchoidal fracture (Jura) of the morro of the same name (with caverns).

*Cariaco.* The hot and petroleum springs which issue from the bottom of the sea in the Gulf of Cariaco, emerge from mica-slate. Farther east on the banks of the Arco near Cariaco, petroleum gushes from secondary limestone which probably reposes on mica-slate.

The numerous boiling springs in the Sierra Nevada itself are said to emerge from a coarse-grained granite. Those of the *Ridge of Quindiu* are discharged from fissures in mica-slate strata alternating with gneiss, and immediately reposing on an immense mass of granite between the basins of the Cauca and Magdalena. This mica-slate is remarkable as containing a considerable quantity of sulphur in its fissures.

Such is the amount of our present knowledge with regard to the positive geognosy of the localities of thermal waters. Notwithstanding their apparent diversity, the reader has already, I have no doubt, begun to class in his own mind these various relations. A certain uniformity of character is perceptible in the geological structure of the environs of these springs, which cannot certainly be attributed to a mere accidental coincidence; and although, in the present state of the science, the number of exact observations is confessedly too small for our being justified in laying down fixed propositions with regard to them on which we could confer the imposing names of laws of nature, still it may not be uncondusive to a more perfect acquaintance with the subject to class under distinct heads the relations which may be at present perceptible, and which may be either modified or generalized by more extended inquiries.

I<sup>1</sup>. There is one class of thermal waters, regarding

<sup>1</sup> Perhaps we might place first in order the exhalations which are discharged from craters of the volcanoes themselves during an

whose parent rock there can be no doubt, the whole series of their relations being immediately cognisable by the senses, viz. volcanic mineral springs in the strict sense of the term,—those which are seen to issue from the sides of still active volcanoes, or from the midst of lavas, which, at a more or less recent period, have been in a state of liquidity. These springs are of the highest temperature, most numerous, and carried on on the largest scale, and with the greatest impetuosity, in Iceland, Ischia, the Phlegræan fields, Java, and other situations where volcanism is exhibited in all its magnificence. Nay, more, it is well known that volcanic eruptions themselves are frequently accompanied by the disappearance of old hot springs and the bursting out of new ones, which disappear with the cessation of the eruption, or appear periodically at the epochs of renewed activity of the volcano.

II. A second class of these waters issue directly from the fundamental granite, or from those primitive schists and newer stratified rocks which, in the present state of our geological knowledge, we are justified in considering as forming merely a mantle-shaped covering to the granite, which is itself, in the greater number of instances, found at no great distance in the vicinity. Under this head may be ranged the different Pyrenean thermal waters: those of central France; of the Alps; of Venezuela; of the north-west of Bohemia; of Portugal, as far as our acquaintance with them extends; of the Riesengebirge; of the north-west of Hungary, and of its Wallachian frontiers; of the Andes of Quindiu.

III. A third class are referable to those independent formations which geologists are now agreed in admitting to be of volcanic origin, such as clinkstone, trachyte,

eruption, consisting chiefly of aqueous vapour and those gases most frequently met with in thermal waters; but, in the present stage of our inquiry, it is my wish to avoid as much as possible whatever might savour of theory, as the proper weight which is due to this phenomenon will come to be fully considered under the head of the Origin of Springs.

basalt, with their porphyries, amygdaloids, and tuffs. These springs are much less numerous than either of the preceding; for, in central France and Hungary, where they attain the highest degree of development, the hot springs can mostly be traced to granite or primitive rocks: and, in the Rhenish provinces, the only other situation where these rocks are very abundant, the hot springs are far from numerous. Under this head, then, may perhaps be ranged Ems, Burtcheid, Bertrich, the Nassau thermals, Teplitz, Erlau, Dax.

IV. Even in those cases where we cannot trace any very evident connexion between hot springs and igneous rocks, either by superposition or vicinity, when they are entirely confined to stratified formations, a case still more rare than either of the preceding, these rocks will be in almost every case so shattered and broken, as to indicate the disrupting agency of a former convulsion of nature. This is the case with the waters of Buda, and of Clifton<sup>1</sup>. The gorge out of which rush the hot springs of Pfeffers in the Grisons described by Ebel, is still more remarkable: it is upwards of 500 feet deep, and not more than 30 feet wide, so that provisions have to be lowered to the baths by means of ropes. Another proof of a great physical change having taken place in the vicinity of Pfeffers, is in the fact that the Rhine, instead of flowing as now north into the Lake of Constance, seems to have been formerly deflected westwards in the direction of the Lakes of Wallenstadt, Zurich, and the valley of the Limmat, owing to the barrier which existed at the Pass of St Liccia, when the mountain appears as if it had been torn asunder. The springs of Baden in Switzerland, and those of Schinznach at no great distance, are near the point where, in consequence of the violent separation of the mountains of Staffelegg and Lagern, the waters of the great basin extending from Coire in the Grisons to this ridge, including the lakes of Zurich and Wallenstadt, escaped by the Limmat<sup>2</sup>.

<sup>1</sup> *Conybeare and Philips* in *Geolog. Trans. N. S. i. pt. 2.*—<sup>2</sup> *London Review* No. 2, p. 327.



V. The last fact which we cannot help observing on an attentive consideration of the position of thermal waters, is their frequent occurrence near the line of junction of two geological formations. This is intimately connected with the preceding, inasmuch as the strongest proof of a difference of geological formation is always considered to be the nonconformity of stratification between two rocks, either directly superposed on, or adjacent to each other, indicating a violent convulsion to have intervened between the respective epochs of their deposition. This is observable with regard to all the thermal waters of England; Matlock and Buxton are placed on opposite sides of the mountain limestone of Derbyshire, at or near its line of junction with the enveloping coal formation. Bath and Bristol are on opposite sides of the lias limestone, the former at its junction with the superior oolite, and the latter with the new red sandstone. Wiesbaden and Soden are precisely at the point of contact of the highly inclined schists of the Taunus with the horizontal alluvial deposits of the valley of the Main. Ax, near the junction of the granite, with the mica-schist formation; Bagneres de Luchon, and Eaux Chaudes, not far from the line of separation of the primitive nucleus of the Pyrenean chain from the superincumbent transition rocks. Indeed, this is by far the most common position of thermal waters when they are not connected with modern volcanic rocks. In Auvergne they are most frequent, near the junction of the fundamental granite with the modern trachytes, basalts and lavas, but are not found in the granitic masses of the Limagne, at a distance from these rocks.

VI. Hot springs issue more frequently from limestone than from any other stratified rock, subject, however, to one or more of the foregoing conditions, so that this rock cannot be considered as their parent formation. This part of their history they share with the common springs of a country, which are generally most numerous, and always of largest size in limestone districts, and which is now considered universally to be connected with the highly cavernous structure of certain of these rocks

favouring the passage of subterranean waters to the earth's surface, in preference to the more continuous sandstone and slaty strata.

Does the geognostic structure of those countries which are destitute of hot springs, confirm any of the preceding propositions? The Bernese Oberland which is without them, consists of an immense cover of secondary rocks. The plains of Bavaria, of Hungary, and of Poland, are principally composed of extensive horizontal strata of the newer sandstones and limestones. None are found in the great Scandinavian peninsula, which is entirely composed of primitive rocks; but here gneiss is the predominant formation, which is scarcely, if at all, penetrated by the oldest granite. Scotland is a country which resembles in its geological characters many districts of the continent of Europe, where thermal waters are tolerably abundant, possessing a central granitic range, numerous plateaux and isolated hills of greenstone, basalt, amygdaloid, and other ancient igneous rocks, and its strata exhibit in many places the dislocating effects of some subterranean force, but as yet it has not been found to possess a single hot spring.

Before concluding the subject of the geognosy of thermal waters, I shall briefly allude to a circumstance which must certainly be regarded as one of the most curious phenomena connected with their history, viz. the intimate sympathy which is observed between them and earthquakes, in parts of the earth very remote from each other. It has been formerly remarked, that great heat or excessive cold, long droughts or abundant rains, influence very little the composition of thermal waters, however notable may be their effects on some classes of cold mineral waters. Earthquakes have been remarked to produce the most striking changes to which they are subject in situations remote from the actual scene of volcanic operations. During the prevalence of these distant convulsions their flow has been sometimes much increased, but more frequently diminished or dried up altogether; their impregnation has been materially changed in quantity and quality. All these changes have been

either merely instantaneous, they have continued for a few hours, days, weeks, at the termination of which, the spring has resumed its former course, temperature, and qualities; or there has continued a permanent alteration in the constitution of the spring.

Of this, the following are a few of the examples on record: On the 26th July 1805, during an earthquake at Isernina, near Naples, the Karlsbad waters disappeared for several hours<sup>1</sup>. In September 1809, without any visible cause, the Sprudel, Theresienbrunn, Neubrunn, and Schlossbrunn, suffered remarkable changes: The last disappeared altogether, and only appeared again in 1823, but of a very different temperature. Many springs and rivers disappeared during the earthquake which devastated Chili in the year 1747<sup>2</sup>. In the year 1824, when different slight shocks were felt in various parts of Germany, the water of the Lake of Massaciucoli in Lucca, suddenly, on the 19th July, after a violent storm, became very turbid, like a solution of soap: this change lasted three days, at the end of which time a number of dead fish were observed floating on the surface<sup>3</sup>. According to Graf, during the last earthquake in Sicily, the sulphureous spring at Gecking overflowed its basin. During the earthquake of the year 1768, the sulphureous thermals of Baden in Austria were violently agitated, rose about a foot above their common level, and disengaged a strong smell of sulphur.

But the most remarkable of these changes, were those observed to take place in different thermals of Europe, during the memorable earthquake of Lisbon, on the 1st November 1755. The *Source de la Reine* at Bagnères de Luchon, acquired a sudden augmentation of temperature. At Bagnères de Bigorre, the heat of the waters was for a moment suspended: the same was observed to take place after the earthquake of 1660. M. Palassou has remarked, that earthquakes, which are frequent in all parts of the Pyrenean Chain, are most destructive on

<sup>1</sup> *Kolreuter*, Charakteristik der Mineralq. 1818; p. 5.—<sup>2</sup> *Journal des Mines*, No. 68, p. 95.—<sup>3</sup> *Annales de Chim. et de Physique*, xxvii. 386.



the Spanish side, where hot springs are rare. On the 1st November 1755, the same remark was made on the waters of Aix in Savoy<sup>1</sup>. Between 11 and 12 noon of the same day, the principal spring at Teplitz began to appear turbid, flowed for some minutes of a dirty yellow colour, disappeared entirely for a few minutes, and reappeared with such violence, that all the basins overflowed; at first the water was still turbid and yellow, but in about half an hour it was as limpid as before these changes<sup>2</sup>. The springs south west of Salins in Savoy, disappeared at the same time for forty-eight hours. Analogous changes took place in the waters of Buda in Hungary. During the same earthquake, many remarkable movements took place in very distant lakes and common drinking waters. Thus, the water of three deep wells in the district of Castel Alfieri in Italy, suddenly became impregnated with sulphuretted hydrogen, in the night of the 30th and 31st October 1755, which continued till the spring of 1808, when it disappeared as suddenly at the time of the earthquake in the valley of Lucerna in Piedmont<sup>3</sup>. On the 10th November 1755, the waters of Neris exhibited some remarkable phenomena: one of the springs was projected to the height of 10–12 feet for some seconds; at the same time the water in the reservoir became turbid like milk, and rose to an unusual height<sup>4</sup>. In connexion with which it may be mentioned that on the 9th November, near the mineral waters of Kannstadt, not far from Stuttgart, there was felt so violent a shock of an earthquake, that a house in the vicinity of the springs was cracked in several places, and sunk several feet<sup>5</sup>. Since the earthquake of 1692, the Pouhont water at Spa, has become much more copious and more strongly impregnated with carbonic acid<sup>6</sup>. Immediately after the earthquake of the 19th February 1822, in Savoy, the waters of Aix discharged a great number of small white bodies resembling the white of eggs<sup>7</sup>.

<sup>1</sup> *Brongniart*, Eaux Min.—<sup>2</sup> *Ambrozzi*, Teplitz, p. 88.—<sup>3</sup> *Bertini*, pp. 167, 168.—<sup>4</sup> *Boirot Desserviers*, Recherches sur les Eaux de Neris, 1822; p. 60.—<sup>5</sup> *Wetzler* über Gesundbr., pt. ii. p. 211.—

<sup>6</sup> *Kastner's Archiv*, v. 228.—<sup>7</sup> *Bibliothèque Universelle*, xxii. 23.

Volcanism has been clearly shewn by modern researches to be one of the principal causes of the stability of the soil on which we tread; and that if volcanoes are celebrated for their destructive eruptions upon the labours and dwellings of man, devastating and depopulating whole districts in the vicinity of their craters,—they must yet be regarded as the safety valves of the globe<sup>1</sup>,—as the guardians against those still more tremendous heavings and oscillations of the solid crust of our planet, which prostrate in an instant the labours and the industry of centuries; nay more, which even raise continents from the bosom of the ocean, or submerge them in its vast abyss. It would be a singular arrangement in the physical constitution of the earth, could such a prerogative be conceded to thermal waters; and that a similar protecting power was possessed by the uninterrupted and comparatively gentle flow of warm springs, which we ascribe to the grander and more imposing phenomena of nature. Such is the opinion of V. Hoff<sup>2</sup>, who has cited various facts in support of the idea, that those parts of the earth's surface where there is a constant and considerable discharge of mineral waters, gases, vapours, &c. are exempt, if not from all internal movements, at least from the more disastrous eruptions and catastrophes. Thus, it is not known that the district round Karlsbad, which is so remarkable for its hot waters and copious carbonic acid exhalations, ever experienced a proper earthquake; and it is not a little singular, that the shocks which in January and February 1824 extended through the mountains of Saxony into the circle of Elnbogen, stopped short within two miles

<sup>1</sup> Many facts might be adduced in illustration of this position; one of these will suffice.

The province of Lima has only one of these spiracles, and it has been repeatedly convulsed by earthquakes, which have more than once levelled with the ground the capital of South America, with its port Callao. The adjacent provinces of Quito on the north, and of Chili on the south, contain numerous volcanic craters, and although tremblings of the ground frequently occur even in them, these scarcely ever assume the fearful character of those in Lima.

<sup>2</sup> *Geschichte der Veränderungen der Erd-Oberfläche*, pt. ii. p. 56.

of these springs<sup>1</sup>. It has been also observed at Wiesbaden, that the earthquakes (in 1620, 1621, 1691, 1692, 1727, 1736, 1756) were much less violent in the vicinity of the warm springs than in other parts of the town<sup>2</sup>. And the inhabitants of Sciacca doubtless owed to the vicinity of their thermal springs their exemption from the numerous earthquakes which have devastated Sicily. From 1740 to 1816, they did not experience a single shock. In the last mentioned year, the tremendous earthquake which lasted for three days in all other parts of the island, was only manifested here by subterranean thunder. Neither did it feel any thing of the violent shocks of 1818, which were so severely felt at Catania. The first violent motions for this very long period were felt during the last days of June and the first of July 1831, which were signalised by the eruption of the new volcanic island from the depths of the Mediterranean Sea, half-way between Sciacca and the Island of Pantelaria<sup>3</sup>.

There, are, however, not a few instances of these terrestrial commotions having been particularly violent in the vicinity of hot springs. In the winter of 1828–29, the earthquakes which were felt from Andernach to Malmedy, in the Rhenish provinces, were especially remarked in the vicinity of the hot springs of Aachen and Burtscheid. Many of the changes just noticed as occurring in thermal waters, have been caused by earthquakes in their immediate environs. In the year 1825, the centre of the most violent movements in the Island of Ischia was the very spot where the hot springs are most abundant, and discharged with the greatest impetuosity<sup>4</sup>. On the memorable 1st November 1755, many of the strongest shocks felt in Switzerland occurred at the town of Bryg, well known for the hot springs in the vicinity. During the earthquake of 1812, a spring in the Elliot's Mine in North America suddenly became hot and turbid, and dried up entirely after a few days<sup>5</sup>.

<sup>1</sup> *V. Hoff*, Geognost. Bemerkungen über Karlsbad, 1825, p. 57.—

<sup>2</sup> *Ebhardt* Geschichte u. Beschreibung der Stadt Wiesbaden, 1817, p. 113.—<sup>3</sup> *Hoffmann* in Poggendorff's Annalen, xxiv. 70, 1831, No. 1.

—<sup>4</sup> *Kastner's Archiv*. xiv. 227.—<sup>5</sup> *Silliman's Journal*, iii. 69.



## COLD SPRINGS.

It was formerly remarked, that a striking uniformity of composition is observable in the greater number of thermal waters; that of all the solid ingredients, the salts of soda were the most abundant, the most constant, and the most universally diffused, associated with various proportions of carbonic acid and sulphuretted hydrogen; and that although the earthy carbonates, oxide of iron and silica, were frequently met with, they were not entitled to be considered as constant and characteristic, and their quantity was almost always very inconsiderable. On examining, however, the composition of cold mineral waters, this uniformity no longer exists; the utmost variety and irregularity seems to characterize their chemical constitution, so as to defy every attempt at methodical arrangement. If, however, we pursue the investigation a little farther, we very soon begin to perceive that there is a certain class of mineral waters closely allied to the thermal in many of their phenomena; with the single exception of the want of an elevated temperature, their composition differs in no material degree from the latter, and is equally characterized by uniformity and constancy; the different salts of soda again predominate, generally associated with a large proportion of carbonic acid: sulphuretted hydrogen, however, is comparatively rare, and the earths are in very small quantity. In position, no less than in composition, is their analogy with hot springs very striking; they are very often found in their immediate vicinity: like them they seem to form distinct groups, connected with mountain ranges; and we will find that there is considerable similarity in the geognostic structure of their environs. Other mineral waters present characters the very reverse of the preceding; the earthy salts and the oxide of iron hold a very important place in their mineral composition; they often contain a tolerable quantity of sulphuretted hydrogen; but the quantity of carbonic acid never equals what we find in the preceding class; and above all, they are distinguished by the total difference of their position,

and of the structure of the country from which they flow. And, lastly, there is the class of brine springs, which has been formerly referred to, whose geognostic relations are equally simple and apparent with those of true volcanic springs.

#### ACIDULOUS AND ALKALINE WATERS.

To the labours of Berzelius, Brongniart, but more especially of Bischof, are we chiefly indebted for the knowledge of the general resemblance which is found to subsist in the structure of the countries where these springs are found, and of their disposition in distinct if not isolated groups. But in order to raise the conclusions which have been drawn by these eminent naturalists to the class of general propositions, there are yet necessary a series of researches, of observations, and of comparisons, which have not been hitherto undertaken, and which cannot be performed by any single endeavours, but must result from the joint co-operation of the whole republic of science. We must beware of allowing the interest of these generalities and analogies to lead us to put too much confidence in them. More numerous and more exact observations may cause them to disappear; but they may, at the same time, strengthen them, which may serve as a stimulus to the zeal of the industrious inquirer into the mysterious operations still going on in the interior of our planet.

*Malvern.* The only alkaline water of England, but which is remarkable from its small quantity of solid matter, is situate on the east side of the chain of hills of the same name in Worcestershire. These hills consist of varieties of granite, syenite, and greenstone; the plain of Worcestershire, on the east side, consists of new red sandstone, which comes up to their base; on the west side they support strata of greywacke and limestone, with encrinites.

The numerous carbonated and petrifying springs of Derbyshire almost all issue in the vicinity of the line of faults which traverses this country, such are those of

*Alpont*, near Yolgrave ; *Brassington*, near Wirksworth ; *Cressbrook Dale*, near Litton ; *Monksdale*, near Tideswell ; *Slaley*, in Bonsaldale ; *Tideswell* and *Wormhill*. We are also informed by Professor Daubeny, upon the authority of Mr Philips of York, that the *Knaresborough* petrifying springs coincide with the direction of a great fault in this part of Yorkshire.

*Vals* has been formerly described (p. 188.) *Jaujac*, at the little town of the same name, on the banks of the river Alignon. It emerges from the foot of the volcano of Jaujac, which rises in the midst of the coal formation. The lava has descended from this volcano north into the valley of Alignon, where it forms, on the banks of the river, a columnar precipice fifty or sixty feet high, and is one of the finest lava streams of the Vivarais.

The different acidulous waters of the *Dreiser-weiher*, in the Eifel Gebirge, the principal of which are the *Stockdreis*, the *Juden-dreis*, the *Dreisader*, and the *Kuchendreis*. This space is situate between the villages of Dreis, Dockweiler, Stroheich, Obereh, and Bruck, about eight or ten miles north-west of Daun, and east-south-east of Hillesheim. According to Nöggerath<sup>1</sup>, this district belongs to the volcanic lakes of this country, as it forms a kettle-shaped depression, surrounded almost entirely by a rocky wall, which is only open on the north-west side by a narrow valley ; and is composed of volcanic sand, entirely analogous to that of the other craters. The village of Dockweiler is built on a basaltic lava, which seems to have flowed from an adjoining hill, where it is wrought for millstones. Bischof concluded, from the application of reagents<sup>2</sup>, that these waters contained a large excess of free carbonic acid, carbonate of soda, a little of the muriate, none of the sulphate, a little lime, and a very minute quantity of iron.

*Biresborn* and *Gerolstein* : two mineral waters which flow from the foot of the extinct volcano near Gerolstein, remarkable for its perfect crater and its lava-streams, which have been poured forth upon a transition lime-

<sup>1</sup> Rheinland-Westphalen, i. 72.—<sup>2</sup> Vulkanisch. Mineralq. p. 164.



stone. The first of these waters contains much carbonic acid, carbonate of soda, a large quantity of the muriate, and some of the sulphate.

*Roisdorf*, near Bonn. Rise immediately below the sand and sandstone, alternating with bituminous shale, at the foot of the range of hills of the tertiary brown coal formation, which extends from Godelsberg to Bergheim. They are about eight or ten miles from the trachytes and basalts of the Siebengebirge.

*Godelsberg*, about four miles south of Bonn, on the left bank of the Rhine, exactly opposite the Siebengebirge. About five miles from this spring, is the extinct volcano of the Roderberg, which extends from Melem up the Rhine, as far as the basalt of Rolandseck, opposite the island of Nonnenwerth. Close by is the basaltic butte of the Godelsberg, and at a little distance that of the Luhnsberg, near Muffendorff.

*Tonniststein*, *Heilbronn*, and *Obermennig*, spring from the volcanic group, on the centre of which is the Lake of Laach.

*Heppingen*, at the foot of the basalt of the Landskrone, in the valley of the Ahr.

*Spa*. From the junction of the transition rocks with the coal formation. Its position is analogous to the thermals of Aachen and Burtscheid (p. 196).

*Löhnberg*, in the valley of the upper Lahn. From pearlstone and amygdaloid. Greenstone, limestone, and greywacke are found in succession to the south. To the north-west rises the basaltic mass of the Westerwald<sup>1</sup>.

*Oberhausen*. From pearlstone and pearlstone conglomerate at the south-east base of the Westerwald basalt.

*Dillhausen*. From greywacke, in the same position.

*Probbach*. From basalt, itself in the same situation.

*Montabaur*. The round hill called the Schlossberg, on which the town is built, rises abruptly from the midst of the strata of greywacke and greywacke-slate of the surrounding country, which are still seen on its south and

<sup>1</sup> *Stiff's Nassau*, p. 423, 421, 183, 396.

west sides. On the north and east, however, is a compact greyish-black basalt, with grains of olivine and magnetic iron, a few crystals of augite, and here and there are seen a few small whitish laminæ of felspar. On the side next the road is a porous grey compact rock, containing fragments of basalt, with a few scattered crystals of augite and glassy felspar, along with magnetic iron (trachyte). At a short distance to the north of Montabaur, at Eschelbach, is a mass of trachytic rocks; and the basaltic formation is of great extent to the east, where it forms the great mass of the Westerwald, with here and there isolated trachytic masses, as at Goldhausen, Niederahr, Schönberg, and Wolferlingen.

*Selters (Lower).* Rises from clay-slate and greywacke, immediately at its junction with greenstone and amygdaloid, which are accompanied by limestone beds. It is not far from the basaltic masses of Fachingen; two of which at Oberbrechen and Weyer are not two miles distant.

*Linholzhausen.* In a great pearlstone formation at its junction with greywacke. Close by is greenstone and amygdaloid.

*Fachingen.* Issues directly from clay-slate. It is situated in the midst of the basaltic buttes which extend between Schaumburg, Diez, and Limburg. On ascending from Fachingen to Birlenbach, the lower part of the valley consists entirely of greywacke-slate, which is succeeded by porphyry, greenstone, and basalt. The greywacke is full of encrinites, terebratulites, and pentacrinites. About a mile to the east is the well known porphyritic mass of Diez.

*Geilnau.* Rises immediately from greywacke slate. About a mile to the north-west is the isolated basaltic butte of the Mühlenberg. On the south-east side this hill consists at its base of a compact basalt, passing into dolerite, with crystals of olivine and augite, and magnetic iron; the weathered surface occasionally shews the presence of felspar; above this compact basalt, a porous variety is met with, constituting the great mass of the hill; the uppermost beds, immediately under the vege-

table earth, are entirely composed of slags, often resembling obsidian and pearlstone, of a reddish or yellowish-grey colour. On the north and north-east sides of the hill, near its base, is found wacke, in which the olivine has quite disappeared, and the augite has assumed a resinous lustre, and basaltic tuff. About two miles to the south of Geilnau, on the opposite bank of the Lahn, is the basaltic mass on which is built the Castle of Schaumburg, at the foot of which are beds of greenstone, amygdaloid, and transition limestone, which, according to V. Buch, has been changed into dolerite by the contact of igneous rocks.

*Rückershausen.* From greywacke. Greenstone and limestone in the vicinity, farther down the River Aar.

*Oberlahnstein,* on the right bank of the Rhine, near the embouchure of the Lahn. From chlorite-slate, containing many particles of oxide of iron; the weathered surface of the rock is of a brown colour.

*Braubach* and *Dinkhold.* From a granular greywacke, often separated into thin laminæ by the presence of micaceous foliæ. The whole rock is strongly impregnated with oxide of iron. Near the Dinkhold springs, it is traversed by a large vein of quartz, four or six feet thick. The Braubach springs contain but little solid matter, in which the oxide of iron and carbonates of lime and magnesia hold a conspicuous place, associated with carbonate and muriate of soda. Both springs contain a large quantity of carbonic acid.

*Marienfels,* on the banks of the Mielbach. From an ash-grey imperfectly slaty greywacke, with numerous micaceous foliæ, which, in the vicinity of the springs, is in many places resolved into a sandy argillaceous mass, and is everywhere strongly impregnated with oxide of iron.

*Sauerthal.* From greywacke.

*Sauerborn,* in the Werkerbach. From greywacke.

*Geroldstein,* in the valley of the Wisper. From clay-slate.

*Fischbach.* From clay-slate.

*Langenschwalbach* and *Ramschied.* From greywacke-



slate and clay-slate, which form the whole of the surrounding country on the north declivity of the Taunus. A great vein of syenite may be traced parallel to the springs through Hambach, Adolphseck, and Breithardt, and a vein of basalt is found at Strinz Margaretha.

*Eltville Salt Spring.* From the quartzose chlorite-slate of the Taunus.

*Cronberg.* From the talcose slate of the south declivity of the Taunus. Much quartz-rock in the vicinity.

On comparing together these observations on the geognostic structure of the environs of the mineral waters of Nassau, all of which possess this character in common, of containing a large excess of carbonic acid, and in most a predominance of the salts of soda, with the excellent chart which M. Stiff has given of this duchy, we arrive at the following very interesting conclusions :

1. One group may be considered as existing in the lateral valleys of Obershausen, Dillhäusen, and Probach, which opens into that of the Upper Lahn. The direction of these lateral valleys is from north-west to south-east ; therefore at right angles to the general direction of the strata of the Westerwald and Taunus hills, which is north-east and south-west. These springs all rise into day at the south-east base of the great basaltic formation of the Westerwald. Their immediate environs consist of numerous alternations of amygdaloid and greenstone, with porphyry and greywacke. Of this group, the Löhnberg springs only have been analyzed, in which, according to Schutz, the sulphate of lime holds a prominent place<sup>1</sup>.

2. The Montaubaur waters may be considered as the type of a second group. They are quite isolated from every other spring. They are placed at the north-west extremity of the Westerwald basalts, exactly the opposite of the preceding. As before mentioned, they contain very little solid matter, in which the carbonate of lime predominates.

3. A third group follows the course of the valley of

<sup>1</sup> *Kastner*, Rep. f. d. Physik, xii. 389.

the Lahn, extending from Oberlahnstein on the west, to Selters on the east. The environs of the spring, situate towards the upper part of the valley of the Lahn, are similar to those of the first group; those in the lower part of the valley issue exclusively from greywacke, clay-slate, and the older schists, and are nearest to the waters of the Rhenish volcanoes. The thermals of Ems belong to this group, all the springs of which contain the carbonate of soda as one of the chief ingredients.

4. Is situate south-east of the preceding. It commences near Lorch on the Rhine, follows the general direction of the valley of the Wiessen, conformable to that of the strata of the district, and terminates at its upper extremity, to the east of Ramschied, in the springs of Langenschwalbach. It is continued in part into the valley of the Aar, to those of Schiesheim and Burgerschwalbach. This is by far the most extensive of all the Nassau groups. It is situate exclusively in the great greywacke formation on the north declivity of the Taunus, and occupies the highest level of all the springs of the duchy. Compared with the groups immediately to the north and south, their quantity of solid matters is small; the earthy salts generally predominate in those towards the centre or highest part of the group; at the two extremities, we find the oxide of iron hold a more conspicuous place, as in the springs of Dinkhold and Langenschwalbach.

5. The fifth group follows the south declivity of the Taunus, also conformable to the direction of the strata of clay-slate of that range. Most of the thermal waters belong to this group. Muriate of soda predominates in their composition.

*Schwalheim.* In the Wetterau, with a composition analogous to those of Soden, at the north-east extremity of the Taunus. Basalt, possessing characters similar to that in the vicinity of Wiesbaden, is found at Usingen, about twenty miles distant from the springs <sup>1</sup>.

<sup>1</sup> *Bischof*, Vulk. Mineralq. p. 182.

*Wildungen*, south-west of Cassel. From the junction of the greywacke and clay-slate formation, with variegated sandstone. Numerous eminences of basalt and clinkstone rise out of the latter formation, which occupies the whole of the country to the north-east, in the environs of Cassel; of these, I shall only name the Weidelsberg, the Lammersberg, the Desenberg, and the Felsberg.

*Dorfgeismar*, about two miles from the town of Hofgeismar. Near the junction of the Jura limestone formation (muschelkalkstein) with the variegated sandstone. Numerous basaltic masses are scattered over the whole of the surrounding country, of which the principal are the Staufenberg, the Gahrenberg, the Schöneberg, and the elevated and extensive mass of the Habichtswald.

*Driburg*. From variegated sandstone in the vicinity of muschelkalkstein. The basalts of the environs of Cassel, on the north side of the Diemel, are about eight miles to the south-east.

*Pyrmont*. From variegated sandstone, close to its junction with Jura limestone. According to the chart of Professor Fr. Hoffmann, the nearest point where we find the basalt of the environs of Cassel is at the Stuckenwardt, on the north side of the valley of the Diemel, about twenty-four miles to the south of Pyrmont. These waters, as well as those of Driburg, issue forth at the bottom of one of those valleys which have been called circular valleys of elevation, the strata dipping away in all directions, from the centre to the circumference. The strata here are the variegated sandstone, muschelkalk, and keuper.

*Johannesberg*, near the town of Fulda. Close by is the Heineberg, the summit of which consists of basalt. On the other side of Fulda, are the basalts of the Frauenberg, Calvariberg, and Petersberg<sup>1</sup>.

*Weyhers*. From an ash-grey earthy lava. About four miles to the north-east is the basaltic group of the Absrod.

*Koden*. Emerges from the foot of the Bilster, a basal-

<sup>1</sup> Voigt, Mineralog. Beschreibung des Hochstifts Fuld, 1794, p. 19.



tic mass which rises perpendicularly about 100 feet above the plain at its base. Numerous basaltic masses in the vicinity.

*Bruckenanu*, *Sinnberg*, and *Wernarz*, on the banks of the Sinn. These three springs are enclosed on the one hand by the Völkersberg, the summit of which consists of basalt; and the Sinnberg, formed entirely of sand and sandstone, but succeeded on the south by the limestone and basalt of the Dreystelz.

*Kissingen* and *Bocklet*, on the opposite side of the Rhöngebirge. Rises directly from variegated sandstone, and the newer secondary limestones. About six miles distant is the basalt of the valley of the Er, and the basaltic Kreuzberg at the distance of eight.

*Alexandersbad*. At the foot of the Kössein, one of the highest of the granitic masses of the Fichtelgebirge. On the line of prolongation of the Kössein, on its opposite side, and about three miles distant from the springs, is the basalt of Waltershofen<sup>1</sup>.

*Steben*. From the vicinity of greenstone.

According to Goldfuss and Bischof, all the eighteen mineral waters which have been hitherto discovered in the Fichtelgebirge, are found in the vicinity of greenstone or basalt. Very few have been analyzed in detail, but most of them contain a considerable quantity of free carbonic acid, many also the carbonate of soda; the oxide of iron, too, holds a prominent place in most of them.

*Elster*, *Brambach*, and *Schönberg*, in the Voigtland. Rise from a marshy plain on the Bohemian frontier. Between these springs and Eger are several hills of basalt; the principal of these is the Steinkopf, near the sources of the Mulda.

*Franzensbad*, three or four miles north of the town of Eger: the district immediately round the springs is of alluvial formation, consisting of clay, loam, sand, and peat. Primitive rocks can be traced to the immediate vicinity of the springs. Basalt occurs at the Plattenberg, near Liebenstein, and on both sides of the River Won-

<sup>1</sup> Goldfuss u. Bischof, Physikal. Statist. Beschreibung des Fichtelgebirges, 1817, i. 105.

dra. About two miles from Franzensbad, to the right of the road to Eger, is the basaltic Kammerbühl, considered by many to possess the characters of an extinct crater<sup>1</sup>.

*Marienbad.* Rise from a marshy plateau at the sources of the Tepel. The fundamental rock is the granite, which extends to Karlsbad, as was distinctly ascertained in 1819, when the springs were cleaned out and newly enclosed; the water, and many streams of carbonic acid, were then found to issue directly from different round orifices in the rock. The Kreuzbrunn emerges from a weathered porphyritic granite, and is not surrounded by the peat bog of the other springs; it also contains much less of the oxide of iron. The highest point of this granitic plateau, which rises between the Böhmerwaldgebirge and the plains of Prague, constituting the true natural frontier of Bohemia, is the Podhora, in the immediate vicinity of Marienbad. Many basaltic masses are in the vicinity; and according to V. Göthe, this rock is found at the highest point of the mountain.

*Königswart* is situate on the same plateau, a little to the north of Marienbad. Its geognostic relations are consequently nearly similar. Close by is the Wolfsberg, composed of basalt, with hornblende and augite.

*Bilin*, at the north-west base of the Bohemian Mittelgebirge, on the banks of the River Bila. Issue immediately from gneiss, but the whole mass of the adjoining range of hills consists of clinkstone and basalt<sup>2</sup>. Borzen, the highest of the mountains which immediately surround the town, consists of clinkstone; the same rock composes the hills of Zelenicz, Schladnig, Gangelhof, Spitzberg,

<sup>1</sup> V. Göthe zur Naturwissenschaft überhaupt, 1817, p. 65 and 232.

<sup>2</sup> About half way between Saatz and Libenz, on the road from Teplitz to Karlsbad, is a very fine view of the Mittelgebirge, which, seen on this aspect, very much resembles some of the views of the volcanic groups of central France, consisting of a series of very regular sugar-loaf cones, rising abruptly from the general level of the surrounding country. Might not this be traced to some relation between their modes of formation? And is there not much analogy both in the composition of the mineral waters of the two countries, and in their relations to these isolated rocky masses?

Prohn, and the colossal Donnersberg, which towers above all the other summits of the Mittelgebirge. Basalt is found at Borezen, Schladnig, Obernitz, Schwarzb-berg, Kohn, &c.<sup>1</sup>

*Liebwertha*, near Zittau. From granite, gneiss, and mica-schist. Basalt is about eight miles distant, at the Keulicht Buchberg, and near Krobsdorf<sup>2</sup>.

*Flinsberg*, on the Lusatian frontier. From gneiss and granite. Basalt is found at the Greiffenstein, in the vicinity; at the Leopoldsberg; at the Merzberg, near Friedberg; and near Langwasser.

*Salzbrunn*. From transition clay-slate, with subordinate beds of red conglomerate and red sandstone, not far from the principal mass of the red sandstone formation. Near Strigau eight miles off, at the Breitenberg near Poischwitz, and at the Rützberg near Keulendorf ten miles distant, we meet with basalt.

*Altwasser* and *Charlottenbrunn*. From red sandstone and the coal formation, with black porphyry and amygdaloid. Basalt occurs at the Spitzberg, Georgenberg, Breitenberg, and Streitberg near Strigau, about twelve miles distant from the springs.

*Cudowa*, in the county of Glatz. From the greensand formation (plänersandstein of Raumer), which is penetrated here and there by the red sandstone. The basalts in the vicinity of Landeck are twenty-four miles distant.

*Reinerz*. Its geognostic relations are nearly the same as those of Cudowa, only that the town is built on primitive rocks, and that beds of limestone are found in the vicinity.

*Niederlangenau*. The principal rock in the vicinity is the greensand formation (quadersandstein), which is penetrated on both sides of the gneiss by insulated masses of primitive rocks. The basaltic masses of the Diber-schaarberg, Grauenberg, and Winklerberg, near Landeck, are about eight miles distant.

<sup>1</sup> *Reuss*, Naturgeschichte der Biliner Sauerbrunn.—<sup>2</sup> *Von Raumer*, das Gebirge Niederschlesiens, &c. geognost. dargestellt, 1819, p. 131.



*Hradek*, near Neusohl in Hungary. From a marshy plain, surrounded on all sides by trachytic conglomerates, often in the state of porcelain-earth. The surrounding country, constituting the valley of the upper Gran, is composed of greywacke, porphyry, greenstone, and amygdaloid, found near Lipe, on the opposite side of the river Gran. Theba salt of St Kerest is about sixteen miles to the SW.<sup>1</sup>

*Tiszoltz*, in the county of Gömor. From the junction of gneiss and mica-schist with red greywacke-slate, in the valley of the Rima. Immediately above the town is a hill composed of compact limestone (mountain). In the valley of the Rima, a short distance above Tiszoltz, a porphyritic greenstone is found resting on the strata of gneiss.

Numerous acidulous waters are cited by authors as issuing from the limestone (mountain) hills which border both sides of the valley of the upper Vag, in the county of Lipto, which form considerable deposits of calcareous tufa, traces of which are found every where in the valley. These limestones rest on greywacke, which itself reposes on the colossal granitic masses of Mount Tatra on the north and Mount Djumbier on the south.

*Lublo*, on the banks of the Poprad, near the Galician frontier. From sandstone of the coal formation, near its junction with the compact (mountain) limestone. The primitive rocks of Tatra, at Wunchendorf, are about twelve miles to the west.

*Barthfeld*, the most celebrated of the numerous acidulous waters of the north of Hungary. From a compact limestone which forms to the north of the town mountains of considerable elevation, covered by the sandstone of the coal-formation.

Numerous acidulous springs are said to issue from the limestone of Mount Borlo, near Szolyva, in the county of Beregh, on the north-east frontier of Hungary. These limestones are succeeded on the north by the

<sup>1</sup> *Beudant*, Voyage en Hongrie, i. 447.; ii. 7. 15. 65. 69. 129. 163. 166. 284. 309. 497.

sandstones of the coal-formation, and on the south by the trachytic porphyries and trachytic conglomerates of Paszika, which are connected with the great trachytic mass of Szeredny.

*Borsek*, on the frontiers of Transylvania and Moldavia. From compact limestone, at the north extremity of the trachytic chain of Mount Margita and Budos.

*Fured*, on the north-west banks of Lake Balaton. From compact grey limestone. This country is remarkable for the numerous plateaux and buttes of basalt, rising suddenly in every direction out of the general level of the surrounding plains, which are chiefly of alluvial deposits on loose sands and sandstones, with beds of lignites. The nearest of these basaltic masses, that of Tihany, is about two miles distant from the springs.

*Parad*, at the north base of Mount Matra, about fifteen miles to the west of the thermals of Erlau. At the junction of the trachytic mass of Matra with the sandstones (lignite) of the plains at its foot. In the vicinity of the village are hills of porphyritic greenstone in a state of decomposition, and containing a great quantity of disseminated pyrites, from which the waters immediately issue. They are ferruginous.

Hardly any of these Hungarian springs having been analyzed, it is impossible to pronounce whether soda is a principal ingredient in their composition. It is however evident, that they all contain free carbonic acid in considerable quantity, from the abundant tufaceous deposits formed by the greater number, from their sensible properties, and from their medicinal uses. The almost total absence of sulphuretted hydrogen is a striking feature in the waters of this country, the only waters in which it exists being the thermals of Buda, situate at the margin of its great central plains, where sulphur is deposited in the different aqueducts and basins of the baths.

*Griesbach, Petersthal, Antogast, and Riepoldsau.* Rise from gneiss at the foot of Mount Kniebis. The nearest basaltic rocks are at the Mahlberg, about fifteen miles to

the south-west<sup>1</sup>. The extensive formation of basalt, clinkstone and trachyte, with tuff, at Kaiserstuhl, is about thirty miles from the springs.

*Innau* and *Niedernau*, in the valley of the Neckar, and *Göppingen* in that of the Fils, nearly in the line of prolongation of the former. Are about ten or twelve miles from the igneous masses at Dettingen and Urach, to the south-east.

*Bar*, near St Germain in Auvergne. From below volcanic rocks, and probably from granite<sup>2</sup>.

*Vie le Comte*, five leagues from Clermont. From the same position.

*Pouques*, in the department of Nièvre. Immediately from Jura limestone or chalk-marl.

In Italy, innumerable cold acidulous and encrusting waters descend from the sides of the different limestone ranges. The most celebrated are those which descend from Mount Belino, in the Roman territory. There is one at the very gates of Rome, which emerges from the foot of Mount Pincio, near the Porto del Popolo, and deposits a tuff much less white than that formed by the Anio. In the kingdom of Naples, although many of these waters emerge from the foot of limestone eminences, we may refer them without hesitation to the volcanic formations in the immediate vicinity. Of these, I need only mention the examples of the concretionary deposits of the *Plain of Acerra*, to the E. of Capoua; of *Calvi*, to the north of the plain of Capoua; and of *Castellamare*, at the eastern part of the Gulf of Naples.

On the north declivity of the Caucasus, all those springs which are of the ordinary atmospheric temperature, contain a large quantity of free carbonic acid. Their geological position is the same with that of the thermal waters of the same groups formerly described.

Such is a brief enumeration of those acidulous and alkaline springs, regarding the particular geological cha-

<sup>1</sup> *Keferstein's Deutschland*, i. 67.—<sup>2</sup> *Brongniart, Eaux Minerales*.



racter of whose localities we have specific details. On referring to the section upon the geographical distribution of mineral waters, many others will be found, of whose probable geognosy a tolerably correct idea may be formed, from what is known of the geology of the surrounding country.

From these observations, it will be seen, that most of the propositions advanced at p. 206. regarding thermal waters may, in the present state of our knowledge, be affirmed, with equal propriety, of the class under consideration. The analogy is most striking with respect to I., III., V. and VI. Not many cold springs are found to issue from primitive rocks; but when they do, sulphuretted hydrogen is more commonly the principal gas than carbonic acid. In the Pyrenean and Swiss springs, for example, the former gas is remarkable for its frequency and abundance. Some very intelligent observers have thought that an intimate relation subsisted between acidulous and alkaline springs, in situations unaccompanied by thermal waters, and the whole tribe of extinct volcanic rocks, such as clinkstones, trachytes, basalts, with their amygdaloids and tuffs. This idea was first formally advanced by Keferstein, who extended its application, in Germany at least, the country to which his observations chiefly apply, to the thermal waters also. He considered<sup>1</sup> that the basalts of that country are so arranged as to form two parallel ranges, traversing it from E. to W., and round which are grouped the mineral waters possessing the characters above referred to: the more northerly passing through the ranges of the Eifel, Siebengebirge, Westerwald, Rhöngelbirge, Hahnbichtwald, Fichtelgebirge, and Mittelgebirge: the more southerly passing through the south of France, skirting the northern and southern base of the Alps, and extending into Hungary and Transylvania. Still greater extension has been given to this idea in the able and elaborate work of Professor Bischof<sup>2</sup>, who has illustrated his views by a copious citation of very interesting ex-

<sup>1</sup> Teutschland, i. 21. 27. 44-47. — <sup>2</sup> Vulkanische Mineralq. Deutschlands u. Frankreich.

amples. But whatever may be the force of these remarks, when applied to cold acidulous waters, they are of very limited application to thermal springs. We have formerly seen, that by far the greater number which do not issue from modern volcanic rocks, can be referred to granitic rocks by actual superposition or a greater or less proximity, and that comparatively few emerge in the vicinity of basalts and trachytes, when granitic rocks are not in the neighbourhood. Nay, in the Pyrenees, and in central France, their temperature is in some degree proportioned to their distance from these ancient volcanic rocks at their proximity to the granitic basis of the country. To avoid the objection of none of these rocks existing in the Alps, where thermal waters are so abundant (none, however, of a very high temperature), M. Keferstein supposes it to be very probable, that the Alps rest upon a volcanic basis, which has only been able to penetrate the superincumbent weight of its vast rocky cover at the base of these mountains, where the resistance to its passage has been the least; but upon this supposition, the hot-springs ought to have been found exclusively along the range of these basalts, which is found not to be the case.

Abandoning, however, these theoretical ideas, and examining the position of acidulated and alkaline waters, when not in the vicinity of granitic or thermal springs, it is seen from the preceding observations, that trachytes and basalts are almost always to be found at no great distance: the number of precise facts, it is true, is as yet but limited, but its generality in those with which we are acquainted, cannot be ascribed to a mere accidental coincidence. The most striking examples on the continent of Europe are the Eifel springs; those in the environs of Cassel; in the Mittelgebirge: and some in Hungary. What value is to be attributed to this connection, will come to be afterwards considered; but, at the same time, I must take this opportunity of reminding the reader, that Britain, which contains numerous examples of the rocks in question, presents a still greater paucity of those springs than even of thermal

waters. Before, however, concluding, it will be well shortly to recapitulate the principal grounds of resemblance between thermal and acidulous or alkaline springs, to which we have been led by the foregoing remarks.

1. In the constancy of their phenomena, and their independence of changes in the atmospheric temperature, dryness or moisture.

2. In their composition; the salts of soda predominating, the earths and oxide of iron occurring in comparatively small quantity; and silica being sometimes found in greater quantity than in the generality of cold springs.

3. They frequently issue from active volcanoes and true volcanic rocks.

4. In situations remote from volcanoes, they frequently accompany thermal waters, when it is not unusual for them to occupy a higher level.

5. Are frequently disposed in linear series, or grouped round the mountain ranges or rocky eminences of a country.

6. Are sometimes found at the junction of two distinct rock formations.

7. The geognostic structure of their environs is very similar to that of some thermal waters.

8. They are not found in the midst of extensive plains, unless when these are interrupted by eminences of basalt or other independent rocks.

#### EARTHY, SULPHUREOUS, AND CHALYBEATE WATERS.

These are remarkably contrasted with all those which have been hitherto considered, by the comparative inconstancy of all their phenomena, their temperature, gaseous and solid impregnation, and their quantity of water, all of which are more or less dependent on the changes of the atmosphere or other external influences. Their quantity of carbonic acid is always very inconsiderable, and different earthy salts generally hold an im-



portant place in their composition. Very rarely do they form distinct groups, but are generally scattered without any apparent regularity over the surface of the plains. An equally striking difference may be observed in the geognosy of the countries from which they issue, as will appear by the following examples.

*Strathpeffer* in Ross-shire, about twenty-five miles from the sea. From a dark-coloured fetid bituminous limestone, which, by weathering, falls rapidly into a loose clay, and which, according to Dr Thomson, contains carbonate of magnesia in large proportion. The prevailing rock of the district is the new red sandstone.

*Vicar's Bridge*, near Dollar. From beds of clay-ironstone in bituminous-shale, subordinate to the sandstone of the coal-formation.

*Bonnington, St Bernard's*, and all the other weak sulphureous and chalybeate waters in the vicinity of Edinburgh. From the shales, slate-clays, and sandstone of the coal-formation.

*Moffat*. Surrounding hills composed of greywacke-slate and transition-greenstone.

*Hartfell*. From a decomposed alum-slate.

*Scarborough*. From the chalk and greensand formation.

*Harrowgate*. From a bog consisting of black, fetid, decaying vegetable matter, which rests on a bed of clay and gravel, succeeded by strata of shale. The surrounding country is composed of the new red sandstone, which is succeeded to the west by the magnesian limestone and coal formations. There are coal-pits in the vicinity of the springs.

*Cheltenham*. From a bed of sand in the blue clay of the lias limestone. Oolite limestone constitutes the Coteswold Hills in the vicinity.

*Epsom* in Surrey. From the plastic clay above the chalk.

*Tunbridge*. From the siliceous gritty sandstone with a ferruginous cement alternating with beds of clay, which forms the Wealds of Kent. It is covered by the chalk-formation which is not found near the springs, but the superposition is seen on the cliffs of the North

**Downs.** In the vicinity of the wells the strata dip away in all directions, as from a common centre.

*Brighton.* From the plastic clay above the chalk?

*Isle of Wight.* From loose quartzose sandstone, containing oxide of iron, which alternates with a blue micaceous argillaceous-slate; and is covered by a blue calcareous marl, with many nodules of iron-pyrites. The upper part of the cliff is formed of a calcareous free-stone, alternating with coarse shelly limestone, containing siliceous nodules: the whole forming a series of beds immediately below the chalk-formation.

*Swadlinbar,* in county of Cavan. The strongest sulphureous water in Ireland. From a compact fetid limestone.

*Johnstown,* in county of Kilkenny. From a ferruginous argillaceous-slate.

*Brownston,* in the same county, which resembles Cheltenham in its properties. From a blue gravelly soil.

*Passy,* near Paris. From below the calcaire grossier, probably from the plastic clay.

*Arcueil, Sevres, &c.* to the south of Paris. Above the formation of calcaire grossier.

*Enghien,* near Montmorency. Above the calcaire grossier, and probably from the gypsum-formation.

*Moulignon,* to the north-west of Montmerency. From the upper beds of the gypsum-formation, below the upper sands and sandstone.

*Provins.* Below the calcaire grossier, and probably from the plastic clay.

*Ferriere,* near Pithivier in the department of Loiret. From the formation superior to the calcaire grossier.

*La Chapelle Godefroy,* near Nogent sur Seine. From chalk, or formations superior to it.

*Forges,* in the department of Lower Seine. From the plastic clay superior to chalk.

*Rheims.* From the same position.

*Roye* in Picardy. From the chalk, or above it.

*Tongres,* near Maestricht. From the limits of the chalk and calcaire grossier, probably from the plastic clay.

*Gamarde* near Dax, in the department of the Landes.

Probably from the inferior beds of the calcaire grossier, or from the plastic clay.

*Weilbach*, in the valley of the Main, near Mainz. From the east side of the Wickertherg, composed of a grey and yellow fresh-water limestone, containing many porous cavities, often filled with brown iron-ore. In some places, it becomes more compact, with an even fracture. It is covered by argillaceous marl, and the loose alluvial deposits of the plain.

*Hochst and Nied.* From the same rocks.

These three springs form part of a range of sulphureous waters which lie at the base of the Taunus range, following the course of the valley of the Main from SW. to NE., and which is continued in the latter direction to those of Frankfurt and Hesse.

*Brakel.* From the muschelkalkstein.

*Meinberg.* From the marls, clays, and sandstone of the keuper.

*Vlotho and Valdorf.* From the same, near its junction with the muschelkalkstein.

*Fiestel, Rehburg, Northeim, Langensalza, and Tennstedt.* From alluvial deposits, chiefly clays and peats.

*Limmer, Nenndorff, and Eilsen.* From the quadersandstein on the margin of the alluvial deposits of the vast plains of the north of Hanover, which contains numerous beds of coal<sup>1</sup>.

*Sonderhausen and Lauchstädt.* From variegated sandstone near the muschelkalkstein.

*Schmeckwitz* in Saxony. From the vicinity of a brown-coal deposit.

In the north of Germany are many chalybeates which emerge from the vicinity of beds of peat, bog iron-ore,

<sup>1</sup> Professor Hausmann considers cold sulphureous springs to accompany so constantly the coal beds of the quadersandstein, that their presence in this formation may be depended on as a sure indication of the vicinity of the combustible, without, however, inferring the absence of coal from the want of these springs. They may occur also in the newer rocks, where there are no traces of coal.—*Ficker's Taschenbuch* for 1816, p. 86.



bituminous wood, and brown-coal; such are those of Bramstedt, Freienwald, Gleissen, and Muskau.

*Pullnas, Seidlitz, and Saidschutz.* From the vicinity of a great brown (?) coal deposit in the valley of the Eger.

These few localities, which might easily be increased to an indefinite number, are sufficient to illustrate the prominent characters of the geognosy of these springs. One of the most obvious of these is, that they are mere local products of the sedimentary formations, which, for the most part, occupy no determinate place in these deposits. Those, however, which present the characters of the class in the most normal form, viz. such as contain a large quantity of *earthy salts* and of the *oxide of iron*, and little if any excess of carbonic acid, seem to issue more especially from the loose and porous sands and sandstones, limestones, marls, and clays of the newer secondary and tertiary formations,—those which penetrate to the smallest depth in the crust of the earth, and which are themselves considered by geologists to be of the most limited extent, and presenting the greatest anomalies in their composition in different parts of the globe. Those which contain a considerable quantity of *sulphuretted hydrogen* gas are very generally in the neighbourhood of beds of fossil combustible matter more or less impregnated with bitumen and iron-pyrites. Thus all the cold sulphureous waters of England either flow directly from, or are not far removed from, the great mass of the coal-formation; and those in the north of Germany are similarly related to the brown-coal deposits of the tertiary and newest secondary formations. It is problematical whether we ought to refer to a *third* order of these springs, a certain tribe which seem to be the most superficial of all,—the last link in the great chain of mineral waters, and most subject of all to the influence of temporary changes,—I mean those which flow from bogs and other situations, where animal and vegetable matter is in a state of decomposition, and which often contain, as in Silesia, immense deposits of the hydrate of the peroxide of iron; or from beds of gravel, sand, or clay, immediately under the vegetable soil.

## SALINE AND BRINE SPRINGS.

These springs, which possess a great uniformity of character in the different localities where they present themselves, are immediately derived from beds of rock-salt, or their equivalent formations, which occupy very extensive spaces on the earth's surface. They accordingly can always be traced in the direction of those rocks which are known to be the depositaries of this fossil, for which reason, the greater number present a very regular disposition in the form of groups. The rocks which chiefly characterize these formations, independently of the saline matter itself, are sandstones, marls, limestones, and gypsum, which are of great importance in influencing the proportions and kinds of earthy salts, which are in most cases found to accompany the proper saline impregnation of the springs. It appears even, that when these rocks do not contain proper rock-salt deposits, so as to give rise to the ordinary economical explorations, they frequently contain numerous and copious salt-springs, which are much more abundant, and more generally diffused, than the mineral itself, and seem to perform in these cases a sort of natural lixiviation of these clays and marls, similar to what is practised artificially in many of our salt-works.

From these and other causes, it is obvious, that great differences must exist in the degree of impregnation of salt-springs, in the absolute quantity of muriate of soda which they contain, and its relation to the other earthy salts. It is probable, from the largeness and simplicity of their impregnation, that they traverse a comparatively limited space in their passage from their subterranean laboratories to the surface of the earth. Sometimes, however, as they are found to issue from rocks which are not known in the present state of geology to be at all connected with salt deposits, the modifications which they undergo must, in these cases, be subject to a greater diversity of character; and it is probable that they are farther removed from the focus of their origin. But

still, if these formations were such as are considered to be superior to the true rock-salt and gypseous deposits, in the order of succession in the crust of the earth, we could legitimately refer them to the latter, either by actual superposition on a greater or less horizontal distance. These different circumstances, however, give rise to three very distinct features in the geognostic position of salt-springs :—those which emerge from true rock-salt deposits, or from those rocks which are considered to be their equivalent formations ;—those which issue from certain newer rocks, which may be considered as among the most recent of the formations of the crust of the earth ;—and those connected with the older rocks, in which we have no evidence of true salt deposits. I must premise, however, that it is with hesitation that I establish this distinction, which, upon a farther investigation of the localities of these springs, may perhaps all be reducible to the first head, without at present referring at all to the theory of the origin of these springs, but merely for the purpose of calling the attention of my readers to three sufficiently curious marks of distinction in their geological position.

First, then, in examining the position of those salt-springs which issue directly from the rock-salt formations, I shall not enter into the discussions which have so much engaged the attention of geologists regarding the place of some of these in the great series of the crust of the earth, which would be in some measure foreign to the proper object of this essay, but shall confine myself to the consideration of the grouping of these springs in relation to the mineralogical structure of the districts from which they flow.

The salt springs to the *south of Newcastle* in the north of England, are situate exclusively in the coal formation : the new red sandstone does not reach farther north than the north bank of the Tees, near Stockton, in the county of Durham.

*Northwich, Middlewich, Nantwich, Shirleywich, Ashby de la Zouch.* From the new red sandstone formation. Near Whitehaven and Chester are extensive quarries



of gypsum and rock-salt, which occur chiefly in its lower beds, resting on the magnesian limestone and coal formations. In Worcestershire, in which are the greater number of the salt springs of England, these beds are reduced to a mere marl.

*Leamington, Tewksbury, Gloucester.* From the lias clay on the eastern side of the southern prolongation of the great new red sandstone formation. The saline springs possess by no means the simplicity of composition of the former; they contain a much larger proportion of the muriates of lime and magnesia, and generally a considerable quantity of the sulphate of soda, a salt of which the others are nearly quite destitute.

*Kingswood, near Bristol.* From the coal formation.

*Melksham, in Wiltshire.* From the oolite formation. With much muriate of lime.

The salt springs of the north base of the Pyrenees are situate in a ferruginous and marly limestone, alternating with clay and gypsum, and generally in the vicinity of masses of greenstone. Most of the springs are but feebly impregnated with muriate of soda<sup>1</sup>. The greater number are situate between the valleys of the Arriege and Sallat; as those of *Salies*, which are the only ones from which salt is now extracted for economical purposes<sup>2</sup>; of *Camerade*; and of *Bastide de Serron*. Considerable gypsum quarries exist at Montsaunes, Bonrepaux, and Lacour. Farther west, in the Department of the Lower Pyrenees, there are several salt springs: the principal are those of *Salies en Chalosse*, which accompany greenstone and gypsum; of *Aincelle* in the valley of Cize; in different parts of the valley of *Soule*; near *Dax*, where they issue directly from the greenstone; and at *Arzet* an abundant spring is found at the bottom of a hill composed of greenstone and gypsum. The gypsum is, in all these cases, subordinate to the clay.

*Chateau Salins, Salins*, and all the other salt springs of the Departments of the Meurthe and Jura, issue from below the compact Jura limestone, and probably from

<sup>1</sup> *Charpentier, Essai*, p. 510.—<sup>2</sup> *Daubuisson, Traité de Géognosie*, ii. 392.

the saliferous gypsum of the keuper, which is below the gryphite limestone of the lias formation.

Numerous salt springs accompany the salt beds of Dauphiny. In the west of Switzerland, in the valley of the Rhone, are the salt springs of *Aigle* and *Bex*. According to Charpentier<sup>1</sup>, the saliferous deposits of Bex are interposed between a limestone and greywacke formation (transition?).

An extensive range of salt springs, many of which are thermal, can be traced in the basin of the Rhine, from Basel as far as Aachen. The greater number of these issue from the extensive new red sandstone formation occupying the whole space between the primitive mass of the Black Forest and the sandstones of the Vosges, such as those of

*Sackingen, Hub, Nauheim, and Salzhausen.*

From the Lower Rhine, considerable salt beds can be traced eastwards to the Weser and the Elbe, which give rise to numerous salt springs, extending from Westphalia to the vicinity of the latter river. Among these I may mention those of

*Anna, Werl, Soest, Westerkotten, Salzkotten*, which issue from the marl of the chalk formation. Close to the first of these springs is the coal formation near Dortmund. And to the south is an extensive greywacke and clay-slate tract, which occupies the greater part of the south of Westphalia to the north of the Duchy of Nassau.

*Salzuffeln*, near Pymont. From the junction of the keuper with the lias formation.

*Pymont, Nenndorff, and Sondershausen.* See pp. 223 and 235.

*Artern.* From new red sandstone.

*Halle.* From the junction of the new red sandstone with the alluvial deposits of Lower Saxony.

*Rosenheim, Reichenhall, and Ischl*, in the Tyrol. From compact limestone without any arenaceous rocks, connected with others where the arenaceous rocks are abun-

<sup>1</sup> Annales des Mines, 1819, iv. 535.

dant, which are covered by a magnesian limestone, regarded by M. Buckland as belonging to the Jura formation<sup>1</sup>.

Salt springs are distributed over an immense tract in Galicia, Hungary, Transylvania, Buckowina, and Moldavia. In the Carpathians, they are all placed near the line of junction of the sandstone of the coal formation, which constitutes the mass of this chain, with the loose sands, sandstones, and alluvial deposits of the plains of Hungary and Poland. None of them are situate in the centre of, or far advanced in, the coal sandstone. On the north side of the chain they form a series extending from north-west to south-east, in which we find those of *Dobromil*, *Dohna*, *Delatyn*, *Kossow*, *Solka*, and *Okna*, in Moldavia. In this line are the great salt-works of *Wielickza* and *Bochnia*, where the rock-salt is contained in a clay interposed between the superficial sands and the coal sandstone. In a similar position, on the south side of the chain, are those of *Sovar*, *Huzt*, and *Visk*.

Numerous salt-springs are scattered over the centre of Transylvania. But we have very little positive information regarding the geognostic structure of this country; all that we know is, that rock-salt is quarried in many places from the midst of a great argillaceous deposit, and that the surrounding hills, on the declivities of which chiefly the salt-springs are found, are composed of sands and sandstones, which render it probable that their geognostic relations are nearly the same as those in the Carpathians<sup>2</sup>. In different points of the frontiers of Hungary there is found a calcareous sandstone alternating with thin beds of limestone, when no salt springs are found. Gypsum is generally in very inconsiderable quantity.

Some salt springs are also indicated as existing near *Zagabria* in Croatia.

Another series of salt springs are those found in alluvial or sandy plains remote from fixed rocks, or from those strata known to be the repositories of saliferous

<sup>1</sup> *Beudant*, Voyage en Hongrie, i. 174.—<sup>2</sup> *Ibid.* pp. 144. 156. 163. 178. 311. 314.



deposits, and generally not far removed from the sea, or other masses of salt water. Of this character are almost all the salt springs of Holstein, Mecklenburg, and Pomerania, and some of those in Hanover and Brandenburg: among which may be enumerated *Oldeslohe*, *Bramstedt*, *Doberan*, *Greifswald*, *Colberg*, *Luneburg*, and perhaps *Elmen* near Magdeburg.

Lastly, there are a few cold salt-springs which issue from older rocks, those which are considered of a date anterior to the deposition of the saliferous formations. Such are those of *Llandrindod* and *Bualt* in Radnorshire, which issue forth in the midst of greywacke and transition-slates; *Werdohl* in Westphalia, from greywacke slate; the celebrated waters of *Kreuznach* near Mainz in the Lower Rhine, which emerge from a porphyry rising out of the midst of the variegated sandstone of the surrounding country; and *Neusalzbrunnen* near Waldenbourg, in old red sandstone. To this head might be referred the saline waters of the thermal class, whose geognostic relations have been formerly considered, and the greater number of which emerge from the primitive crystalline and schistous rocks.

With this I close these observations on the geognosy of mineral springs, in which I have endeavoured to state simply their relations to the rocky masses which enter into the composition of the crust of the globe, independently of all theory regarding their probable origin or manner of formation. The scantiness of these facts will be apparent to all; indeed they can only be considered in the light of an outline of a more extensive edifice, for the completion of which we must depend upon the co-operation of every zealous naturalist.

It will not, perhaps, be amiss at present to connect the subject of the present chapter with that of the preceding, and to adduce a few of the generalities which, in the present state of the science, we are capable of establishing between the composition of mineral waters and the rock formations from which they flow:

1. The salts held in solution in mineral waters have

often no connection with the acid, saline, or earthy matters, which enter into the composition of the rocks which they traverse in their passage to the surface of the earth, which seems to be the first index that such waters cannot derive their origin from these formations.

2. The mineral waters of the primitive formations are almost all thermal, and generally possess a very high temperature. Their predominant impregnation is usually sulphuretted hydrogen gas, free carbonic acid, carbonate of soda, and, in general, salts with a base of soda, silica, few calcareous salts, except the carbonate of lime in some peculiar situations, and but a small quantity of iron.

3. The waters of the transition and older secondary formations participate in the properties of those belonging to the primitive rocks. They are generally of a lower temperature, though some of them are still very hot; free carbonic acid is much less common; and sulphuretted hydrogen is almost entirely absent. Salts of soda still predominate, but the carbonate is not so common; and the sulphate of lime is found in the greater number of these waters. Silica exists only in two or three examples.

4. The waters of the newer, secondary, and tertiary formations are as distinctly characterized as those of primitive rocks, placed at the other extremity of the series. They are all cold. Free carbonic acid is almost entirely absent. Their predominant ingredients are the carbonate and sulphate of lime, sulphate of magnesia, and oxide of iron.

5. The trachytic and basaltic formations, and modern volcanic rocks, present in their mineral waters many of the circumstances of temperature and composition which are found in the waters of granite and other primitive rocks. Sulphuretted hydrogen, carbonic acid, carbonate of soda, carbonate of lime, and silica reappear, and many contain the free sulphuric and muriatic acids. The sulphate of lime, magnesian salts, and oxide of iron, are again wanting. Thus, even in the present imperfect

state of the science, the phenomena of mineral waters coincide with other geognostic observations, in placing below the granite the origin of the volcanic formations.

6. It is often found that the mineral waters of a district have almost the same composition, in which case they generally issue from the crystalline and independent formations. In other cases they are subject to great varieties within a comparatively limited space, so that waters of a totally different composition rise close to each other, when they emerge from sedimentary rocks.

7. We very commonly observe in mineral waters certain associations of salts, which, though not constant, are sufficiently general to merit our attention<sup>1</sup>. *a.* Carbonate and sulphate of lime most frequently accompany each other: *b.* Carbonate of magnesia is always accompanied by carbonate of lime, but not *vice versâ*: *c.* Carbonate of soda is generally accompanied by the sulphate and muriate of the same alkali, but not *vice versâ*: *d.* Sulphate of magnesia is generally accompanied by the sulphates of soda and lime, but not *vice versâ*: *e.* Sulphate of iron and alum are generally associated: *f.* Muriate of soda is always associated with sulphate of lime, if carbonate of soda is not present: *g.* Sulphate of lime is found in most springs, and accompanies all salts except carbonate of soda: *h.* Muriate of magnesia is generally found along with muriate of soda, but not *vice versâ*; is often found also with the sulphate of magnesia: *i.* Muriate of lime is almost always accompanied with muriate of soda.

8. It is a remarkable phenomenon that mineral, and more especially thermal, waters contain a much larger proportion of sulphuretted hydrogen and carbonic acid gases than they could be capable of dissolving under the ordinary pressure of the atmosphere, and at the given temperature (see pp. 32 and 38), which shews that they have been charged with these gases under a high pressure, and have traversed canals sufficiently close to prevent the disengagement of the excess of gas thus compressed.

<sup>1</sup> *Kirwan on the Analysis of Mineral Waters*, p. 31.



9. In the last place, one of the most remarkable phenomena in the history of mineral and thermal waters, and that which, perhaps of all others, is most fitted to excite our astonishment, and most worthy of the profoundest meditations, is the constancy of all their characters throughout a long succession of ages.

## SECTION IV.

### ROCKS FORMED BY MINERAL AND THERMAL SPRINGS.

MINERAL waters are not less interesting when viewed under this aspect than under any of those which we have already considered. The actual quantity of insoluble matters capable of being deposited in concretionary masses, which they hold in solution, is so small, that it might at first sight seem a little strange to talk of mountain rocks owing their formation to these apparently insignificant agents. Our surprise will, however, vanish when we consider for a moment that nature is not like man, in his little experiments, limited within the narrow bounds of a comparatively short period of time, but that, in the long succession of centuries, she may, by the accumulated operation of very imperceptible causes, produce effects modifying, to a very important extent, the physiognomy of the earth's surface. To the geologist, accordingly, the examination of these rocks becomes an object of the highest importance, both from the prominent place which they hold in the newest formations of the great series composing the crust of the globe, but also from their utility in enabling him, from the observation of phenomena which are daily passing before his eyes, to form probable conjectures, if not a positive explanation, of the causes which have presided over the formation of masses possessing a similar mineralogical structure, and occupying a somewhat analogous position on the earth's surface, but whose origin is of a date anterior to historical epochs, and perhaps also to the pre-

sent order of things. Indeed it results more and more every day from the recent observations of geognosts, that the calcareous tufas, which owe their formation to mineral waters, in the most extended acceptation of that term, although commonly separated into two classes, those whose mass has ceased to admit of any increase, and which belong to an ancient order of things, and those evidently formed and still increasing by the accumulated deposition of these springs, are separated from one another by no well-marked—no characteristic—line of demarcation. And an eminent geologist of the present day, to whom we are indebted more than any other for our knowledge of these recent geological formations<sup>1</sup>, has affirmed, that, after examining on the spot the relations of the ancient and the modern travertino, and observing the mode of origin of the latter, he was led to consider waters issuing from the interior of the earth, and holding in solution different rocky matters, as one of the chief agents in the production of the greater part of the compact fresh water and marine limestones.

The consideration of the deposits of mineral waters is of not less importance to the chemist who would arrive at a perfect knowledge of their chemical constitution. Many of the rarer ingredients which have of late years been detected in some springs, would never have been found to exist from their very minute quantity, but from the previous examination of the sinters and tufas deposited by the waters in which they exist in a higher degree of concentration. It was from his having first detected the presence of fluoric acid, phosphoric acid, strontian, and manganese in the *Sprudelstein*, that Berzelius was led to examine and demonstrate their existence in the Karlsbad water itself; and the analysis of the Wiesbad sinter shewed Kastner that these springs contained manganese, fluoric and phosphoric acids, hydrobromate of magnesia, with minute traces of ammonia and hydriodic acid<sup>2</sup>; and phosphoric acid, alumina, oxide of manganese, and perhaps strontian, were first de-

<sup>1</sup> *Brongniart*, Description Geolog. des Terrain de Paris. Second edition, 1822, pp. 317. 319.—<sup>2</sup> *Kastner's Archiv*. ix. 383, 384.

tected in the thermal waters of Auvergne by the examination of the tuff composing the remarkable natural bridge of St Allyre<sup>1</sup>. Nay, more, it is not improbable that, by the examination of the deposits of springs, ingredients will be found to be discharged from the earth by these great natural lixivia of the rocky strata composing its crust, which, at present, they are not suspected to contain.

I have thus attempted to sketch very briefly the importance and interest which attaches to the investigation of the mineral deposits of springs; but it would lead me far beyond the bounds of this essay to enter upon the consideration of all these details, but which certainly might be the object of a work of much interest on the geology of the most recent formations. I must confine myself at present to a brief statement of the chief rocky deposits which have been formed, or are still forming, by the springs which continue to flow from the earth's interior. Different arrangements might be adopted of these deposits. They might be classed as ancient or modern, as formed by thermal or cold springs, according to the chemical ingredient predominating in their composition, or in a simple mineralogical order. I shall adopt the chemical arrangement as the most simple, and as that which is based upon the most important of their distinctive characters. The following is a tabular view of the more important of these varieties :

#### I. CALCAREOUS—

1. Calc-sinter, fibrous calc-sinter, or stalactites and stalagmites:  
*e. g.* Incrustations lining caves and caverns.
2. Calc-tuff, incrusting limestones, tufaceous limestones:  
*e. g.* Starlyburn in Fifeshire, St Allyre and Arcueil in France, Karlsbad.
3. Pisolites, pisiform limestone, peastone:  
*e. g.* Karlsbad, Vichy, S. Philippo in France.
4. Travertino:  
*e. g.* Environs of Rome, Messina, Czegled in Hungary, Guancavelica in South America.

<sup>1</sup> *Berzelius' Karlsbad, &c. p. 106.*



## II. SILICEOUS—

1. Common siliceous sinter:  
*e. g.* Iceland, Lanzerote.
2. Opaline siliceous sinter:  
*e. g.* Iceland.
3. Gelatinous silica:  
*e. g.* Mont d'Or, Poorgootha in India.
- ? 4. Opal:  
*e. g.* Hungary.
- ? 5. Allophane.

## III. ALUMINOUS (MECHANICAL)—

1. Boles:  
*e. g.* Iceland, Nassau.
2. Mud (Moya):  
*e. g.* Iceland, South America.

For the mineralogical discrimination of each of these varieties, I must refer my reader to the different systems of mineralogy<sup>1</sup>: in this place I shall confine myself to a short account of the different situations where they exist, and the prominent characters of their composition.

I. *Calcareous*.—All these calcareous depositions, notwithstanding the immense masses which they present on the surface of the globe, have at some former epoch been held in a state of true chemical solution by the water of springs. The agent which effected this solution both in thermal and cold springs was in every case a greater or less excess of free carbonic acid, which, being much more loosely combined with, and escaping much more freely from, warm springs, these deposit the calcareous matter more rapidly than cold<sup>2</sup>.

<sup>1</sup> *Vid. Jameson's Manual of Mineralogy, 1821.*

<sup>2</sup> It has been fully established by the experiments of Bergman and Cavendish,

1. That, when the proportion of water to the carbonate of lime is very considerable, for instance as 12000 : 1, then the weight of carbonic acid necessary to keep the lime in solution is about one-half the weight of the carbonate of lime; and if the proportion of water is still greater, a still smaller weight of carbonic acid is required, so that at last the quantity of water may be such that no excess of acid whatever will be required to keep the carbonate of lime in solution.

2. Conversely, the smaller the proportion of water with respect

The most striking differences in these concretionary limestones consist,—1. In their greater or less compactness; in most cases they contain numerous rounded or elongated cavities, of greater or less dimensions, which are either empty or lined with a thin coating of the hydrated oxide of iron. These cavities evidently owe their formation to the vegetable matters which have been enveloped by the calcareous matter at the epoch of its deposition, but have subsequently been resolved into their proximate elements, leaving cavities in the space which they formerly occupied. The ferruginous matter lining their walls is formed by the force of the cohesion of aggregation attracting the different particles disseminated through the mass of the rock into those situations where they are most at liberty to develop their proper crystallized forms. At one time it was supposed that this character of compactness and porosity might serve to distinguish the ancient from the modern concretionary limestones, as they were then called. Later observations, however, have shewn that no reliance can be placed upon this character, for the purpose for which it was suggested. It is true that the Roman architects knew very well how to distinguish the ancient or inferior from the modern travertino, the former, from its compactness and solidity, being the only kind capable of being employed in the construction of edifices. But the distinction is only relative, and does not inform us at all if what is called the ancient travertino dates from a period anterior to historical records. There are besides many instances where an insensible transition can be observed from the deposits actually forming by calcareous springs, and with the most highly marked cellular structure to compact limestones, fit for being employed as building stones, and which cannot be distinguished in hand specimens from the most perfectly characterized Jura limestones. I shall only select, in illustration, an example adduced

to the carbonate, the greater must be the excess of fixed air necessary to keep it in solution within the limits above mentioned.

3. If the weight of the carbonic acid in union with the water exceeds that of the carbonate of lime, it will dissolve it, however small its volume may be with respect to that of the water.

by MM. Lecoq and Bouillet, in their account of Auvergne<sup>1</sup>. On the north side of the little town of Nouette, on the right bank of the Allier, are limestone quarries, the only ones in the whole department, which, although they present all the characters of a Jurassic limestone, are nothing else than a travertino covering the declivity of an enormous mass of basalt. This limestone rests on an arenaceous deposit, consolidated by the calcariferous waters; and we can trace all the passages from the most compact travertino to earthy and cavernous masses, surrounding a tolerably copious acidulous spring, the water of which is slowly incrusting the mosses surrounding its channel; and we are informed that the waters of Civita Vecchia, in the Campagna di Roma, deposit not only a yellow travertino, but also a white granular limestone like marble, and that there is an insensible passage between these varieties<sup>2</sup>.

2. In its colour, being sometimes pure white, at others yellow, grey, brown, or even quite black, as in some varieties of sprudelstein. When white it often assumes the *fibrous* texture, and cannot be distinguished by its external characters from some varieties of arragonite: and it is remarkable that Berzelius always found this white, compact, fibrous variety, to contain a notable quantity of strontian<sup>3</sup>. The darker varieties generally

<sup>1</sup> Vues et Coupes d'Auvergne, 1830, 8vo. p. 131.—<sup>2</sup> *Lyell's Principles of Geology*, vol. i. 1830, p. 198, &c.

<sup>3</sup> The following is the composition of a very compact *fibrous* variety of Sprudel stone, but possessing a brownish tint. Its specific gravity was 2.86. (The travertino of Nouette in Auvergne has a specific gravity of 2.58, and that of Coude, 2.70). In 100 parts:

Carbonate of lime,	. . . . .	97.00
Fluate of lime,	. . . . .	0.69
Carbonate of strontian,	. . . . .	0.32
Phosphate of lime,	} . . . . .	0.59
... of alumina,		
Oxide of iron,	. . . . .	1.40
Water,	. . . . .	
		<hr/> 100.00

Berzelius' Karlsbad, p. 57. Most specimens of Sprudelstein behave before the blowpipe exactly like arragonite, swelling up and falling into a mealy powder; and this character is the more distinct the more fibrous the specimen.



owe their colouring matter to vegetable impurities, or to the oxide of iron; sometimes the latter amounts to a very considerable quantity. Berzelius found upwards of 19 per cent. in a *black* specimen of the tufaceous vault of the Sprudel<sup>1</sup>. Indeed the shade of colour of the calcareous deposits of the Karlsbad waters is exactly proportioned to the quantity of oxide of iron, the whiter varieties consisting of nearly pure carbonate of lime. The access of light being necessary to give it a brown or yellow tint; what is deposited in the orifices and fissures by which the water is discharged is nearly quite white sinter; and the fragments which were broken from the innermost of the vaults inclosing the reservoir of hot water (see p. 199), and of course completely excluded from the light of day, were quite white, or only spotted here and there pale red, and resembled calcedony very much in external appearance<sup>2</sup>.

<sup>1</sup> It may be interesting to compare the composition of this variety with the former. 100 parts contain—

Carbonate of lime,	.	.	.	43.20
Phosphate of iron,	.	.	.	1.77
Oxide of iron,	.	.	.	19.35
Carbonate of iron,	.	.	.	12.13
Phosphate of alumina,	.	.	.	0.60
Silica,	.	.	.	3.95
Water,	.	.	.	9.00
				<hr/>
				100.00

<sup>2</sup> Not a few, perhaps, of the enigmatical phenomena of the Italian travertinos might be elucidated by a reference to the Carlsbad sinters and tufas. The compactness of the *Sprudelstein* seems entirely to depend upon the degree of approximation into which the particles of carbonate of lime are brought by the impetus of the water at the moment of their deposition. Those varieties which are capable of being polished and used as ornamental stones, are all formed in situations where the water is projected in sudden jets, or flows with rapidity over a narrow and confined channel; while those formed in the basins, pools, and slow flowing channels, even when the water has as yet lost none of its caloric, are porous, sandy, and more friable. And the old calc-tuff, which was formerly much used for burning to quick-lime, but is now in great request for ornamental purposes, is as hard and compact as ordinary limestone; it has a remarkable fibrous fracture, and forms layers and alternations of different shades of colour, giving it a very agreeable appearance when polished, such as black, brown, yellow, grey, flesh-coloured, and white. A somewhat analogous process to what is here performed by nature seems to be taken advantage of at the baths of

3. In the degree of purity of the carbonate of lime. Besides the vegetable matter and oxide of iron already referred to, silica is the most important of the subsidiary ingredients. Its quantity, however, is but small, the tuff of the natural bridge of St Allyre, one of the most highly silicified, containing 6.8 per cent.; and it is curious that it seems to be generally most abundant in the black varieties; farther observations, however, are necessary to establish this fact with certainty. Strontian is another ingredient, which, though much more uncommon, has of late years attracted attention, and has been found to be much more common in these tufas than was formerly supposed. One of the most interesting of these examples are the waters of St Nectaire, in central France. All the fissures of the granite from which they emerge to the surface of the earth are lined with a multitude of delicate acicular crystals of white arragonite, interwoven together in all directions. In some of the fissures a bluish substance has been deposited simultaneously with the arragonite; but the latter is always found in contact with the granite. It is only subsequently to its formation that the different travertinos have been formed which occur in considerable masses on both sides of the rivulet. These travertinos have in some places enveloped reeds and shells; they are both cavernous and compact, rarely white, but generally coloured by oxide of iron or vegetable matter. Different siliceous deposits seem to have been formed along with the travertinos, one of which, of a fine black colour, was found when searching for thermal waters at the foot of Mont Cornadore. In the cavities of the travertino are often found masses of friable yellow ochre, and small lamellar crystals of white calcareous spar. These different substances are never confounded together, but are always separated into distinct layers by thin deposits of travertino<sup>1</sup>.

St Filippo in Tuscany, for the formation of artificial stone medallions in basso-relievo.—(*Dr Gosse* in *Edin. Phil. Journal*, ii. 1820, p. 297.)

<sup>1</sup> *Lecoq et Bouillet*, Auvergne, p. 117.

4. An interesting modification of structure, experienced by the calcareous deposits of springs, is where they assume the globular or oolitic texture, from the analogy which in such cases they present in their external characters with some of the secondary limestones, which form immense strata in the crust of the earth. This is well seen in the travertinos of San Filippo and of Tivoli. Some of those at the former place, we are informed by Professor Lyell, cannot be distinguished from the magnesian limestones of Sunderland in their external appearance; and at the latter there are beautiful alternations of stratified travertino, globular travertino, and pisolites.

5. The last of the differences among these concretionary limestones which I shall notice, and that which is perhaps of most interest to the geologist, depends upon their position on the earth's surface. I shall pass over the stalactites of caverns, which are scattered in great numbers over limestone districts, and are formed by the infiltration of calcariferous waters, as they are not so immediately connected with mineral springs properly so called, and as probably the particles of carbonate of lime are separated from their menstruum by a process somewhat different from true calcareous waters.

Sometimes the calcareous matter forms encrustations of greater or less abundance, covering the rocky cliffs or hills over which the water flows after its emergence from the interior of the earth. Of this there are the well known examples in this country of Starley Burn, near Edinburgh, and Knaresborough in Yorkshire; and in Italy the numerous cascades and waterfalls which descend from the chain of Monte Velino, such as those of the Teverone and Tivoli, which form a sort of barrier across the valley, and produce those beautiful cascades for which this classic spot is so remarkable, and the deposits of the Terni at the confluence of the Velino and the Nera, to which we may add the springs of Arcueil and Sevres, near Paris, of St Allyre in Auvergne, and of Guancavelica in South America. This is by far the most common form in which the limestones of modern



springs are deposited. Generally speaking, these encrustations are more porous than some of the other forms, and contain a greater quantity of vegetable fibre and other organic matter; but this is in a great measure a mere accidental circumstance, depending upon the degree of agitation to which the water is exposed. When the calcariferous water happens to flow into inclosed basins or lakes, it forms deposits of much greater thickness, and which bear much resemblance to some of the newer fresh water limestones, containing like them fresh water shells. Of this one of the most interesting examples are the lakes of Tartari and Solfatara, the tufa of which is very compact, and resembles in its characters some of the fresh water limestones<sup>1</sup>. To this class of deposits must in all probability be referred the great travertino quarries of the Ponte Lucano between Rome and Tivoli, which is not improbably the work of an ancient sheet of water, the only remains of which are the two small lakes just noticed<sup>2</sup>. Great masses of calcareous matter are forming at the bottom of a lake near Batavia, in the Island of Java, which disengages abundant streams of sulphuretted hydrogen gas<sup>3</sup>. The tufaceous vault of the Karlsbad waters, which is situate in a deep ravine in granite, presents phenomena altogether peculiar to itself. (See p. 199.)

The third case in regard to the position of these calcareous deposits is, where they are placed at an elevation, or in situations such that they could not have been deposited by the springs in their present state. Sometimes they even form hills of considerable elevation. For the theory of their formation in these localities I must refer my reader to the excellent account of M. Brongniart (*Description des Environs de Paris*, 1822,

<sup>1</sup> *Brongniart in Cuvier's Oss. Fossiles*, 2d edit. ii. 550.

<sup>2</sup> *Omalius d'Halloy, Journal des Mines*, xxxii. 405. *Breislak* mentions (*Instit. Geolog.* ii. 123.) that this travertino, when first taken from the quarry, is quite white, it, after a time, becomes yellowish, and at length assumes the reddish tint, so characteristic of the Coliseum and other buildings of ancient Rome, as well as of the much older Grecian Pæstum.

<sup>3</sup> *Abel's Narrative of a Journey in China*, 1818.

p. 312-319). The most remarkable of these masses, which owe their formation to the agency of springs, is the hill of Colle, on the road from Sienna to Volterra; and the hill on which is placed the village of San Filippo, which is more than a quarter of a league in length, by about 300 paces in breadth<sup>1</sup>. In the counties of Trentsen, Lipto, &c. in the north of Hungary, there are immense tufaceous deposits formed by the numerous acidulous waters of this country; these form in some cases hills of considerable extent<sup>2</sup>; and the distinguished geologist just named considers the hills of travertino which bound the valley of the Elza, in Tuscany, to owe their formation to streams actually existing and depositing tufa, and which, before the excavation of the valley, flowed out at a higher level, and deposited the tufa on the summits of the hills which bound the valley. It is remarkable that, although carbonic acid bubbles up from many springs now flowing from the bottom of the valley, none of these deposit tufa. The tufa deposited by the baths of Vignone, in the valley of the Urcia, is calculated to increase at the rate of half a foot annually. It now forms a cover of immense thickness to the highly inclined strata of black slate, limestone and serpentine, of the Apennine formation, which form the lower part of the hill. Many of the Caucasian thermal springs have deposited, and still continue to deposit, great masses of calc-sinter. The south declivity of Mount Maschuka, to the height of 400 feet, is a great mass of fibrous sinter, from which hot springs still issue. At Kislawodsk and the Katherinenquellen there are very extensive ancient tufaceous incrustations; but the present springs deposit no carbonate of lime.

Lastly, there are instances of the calcareous matter of mineral waters agglutinating together the arenaceous

<sup>1</sup> "The column of water which supplies the baths of St Filippo is about nine inches in diameter. It falls into a pond, constructed about twenty years ago, where it has since deposited a solid rounded earthy mass more than thirty feet thick." Vide *Gosse* in *Edin. Phil. Journal*, ii. 292. These observations were made in the year 1818.

<sup>2</sup> *Beudant*, *Voyage*, ii. 129; iii. 291.

and gravelly particles of the channels over which they flow, giving rise to a true calcareous breccia or sandstone. Thus near Coudes, on the banks of the Allier in Auvergne, is a conglomerate, the cement of which is an "arragonite" of quite recent formation, all the relations of which indicate that it has been formed by mineral waters, as it is covered by great masses of travertino, which, like itself, rest on the arkose and granite. In the vicinity of the mineral waters of Tambour are alternations of a breccia and recent limestone, with thin layers of arragonite interposed. The waters of Medaguas also, which issue from the bed of the Allier, flow over a conglomerate consisting of fragments of basalt cemented by arragonite; the arragonite is most abundant near the spring; at a little distance it is a simple travertino more than usually translucent: and still farther down the stream is a calcareous sandstone, which is nothing else than the sand of the Allier cemented together by the carbonate of lime deposited from the spring. Similar phenomena are observable in the grotto of Mont Cornadore, the roof of which consists of rolled masses cemented together by travertino of the waters of St Nectaire<sup>1</sup>.

Such is a rapid outline of the most important features in the history of the calcariferous deposits of mineral springs. Were it not to exceed the limits of this essay, I might touch upon certain classes of deposits of great interest, which are by no means foreign to the matter in hand, and are well calculated to enlarge our ideas of the extent and variety of relations in the doctrine of mineral and thermal springs. I allude to those fresh water limestones daily forming at the bottom of certain lakes, by a process very analogous to the concretionary deposits of mineral waters; of which we have excellent illustrations in the lakes of Forfarshire, described by Professor Lyell<sup>2</sup>; and the marshes of Czegled, described by M. Beudant<sup>3</sup>: and those other marine concretions

<sup>1</sup> *Lecoq et Bouillet*, pp. 27, 34, 67, 118.—<sup>2</sup> *Geolog. Transactions*, series 2d, ii. 73.—<sup>3</sup> *Voyage*, ii. 353.



arising from the agglutination of the sands, shells, and coral fragments of the sea shore, especially of tropical regions, of which we have the notable examples of the coast of Sicily, near Messina, described by Spallanzani,—the concretionary limestone which enveloped the Carib skeleton on the coast of Guadaloupe,—the modern oolite of the shores of the Island of Palmas, described by V. Buch<sup>1</sup>,—and the recent shell limestone and sandstone mentioned by Dr Davy as occurring near Jaffnapatam and Negombo, in the Island of Ceylon<sup>2</sup>.

II. *Siliceous*.—These are neither so abundant nor so generally diffused as the calcareous, and they are almost entirely the products of thermal waters situated in true volcanic countries. For the type of these deposits we must certainly resort to the Island of Iceland, the spot where they exist on a scale of the greatest magnitude. Indeed it would seem that the solution of silica was the greatest effort of thermal waters, and that accordingly it is deposited in those localities only where they have attained the maximum of their development.

In Iceland the principal of these deposits surround the Great Geyser. This spring has formed round its orifice a mound about seven feet high, consisting of rough irregular siliceous masses, which rest upon older and more regular beds of a similar origin. The line of demarcation between the older and the newer depositions is said to be quite distinct. The encrustations are in some places worn smooth by the overflowing of the water; but most generally they rise into numerous cauliflower-looking tufts, covered by a soft crystalline efflorescence, which gradually hardens by exposure to the air. The depositions are visible to a great extent for the distance of more than half a mile all round the springs, and are in many places of great thickness. In one place, at a short distance from the Geyser, Sir G. Mackenzie mentions the existence of a large irregular opening, nearly full of water, as clear as crystal, and per-

<sup>1</sup> Beschreibung der Canarischen Inseln, p. 258.—<sup>2</sup> Account of Ceylon, 1821, p. 12.

fectly still, though nearly at the boiling point, through which were seen a variety of the most beautiful white incrustations, and the eye was carried into a vast cavity, over which these deposits seemed to form a dome of no great thickness : so that it is not improbable that the little valley from which the Geysers issue is nothing else than a vast siliceous vault covering the subterranean reservoir of hot water, like the calcareous dome of the Karlsbad Sprudel. Siliceous deposits are formed, though not so abundantly, by many of the other hot springs. Those of Reikum, described by Sir J. Stanley, are principally remarkable for the deposition of some siliceous matter, which to the eye resembles calcedony, but with its transparency it has not the same hardness, as, when pressed between the fingers, it crumbles to pieces<sup>1</sup>.

Another beautiful display of the siliceous deposits of springs is in the valley of Furnas, in the Island of St Michael's, one of the Azores<sup>2</sup>. Wherever the water flows are found abundant incrustations of siliceous sinter. All round the Caldeiras or basins of hot water are older deposits, which are separated into distinct layers. Another form in which the sinter occurs is that of delicate snow-white crusts, in slender filaments, interlacing each other ; or in that of stalactites, from two to three inches in length. Wherever the thermal waters come into contact with vegetables, these are quite changed into siliceous matter, which assumes the most beautiful arborescent forms. In one situation there is a bed of wood from three to five feet thick, entirely changed into silex ; and a mass of reeds, which has in another place undergone the same process of mineralization, presents in the centre of the joints the most perfectly formed crystals of sulphur<sup>3</sup>.

<sup>1</sup> For a more detailed account of the singular phenomena of the Icelandic springs, the reader may consult, *Sir J. Stanley's Account of the Rycum and Geyser springs in the Edin. Phil. Trans.*, 1794, iii. 127 and 138 ; his observations were made in 1789 ;—and *Sir G. Mackenzie's Travels in Iceland*, 1811, p. 212, *et seq.* ; his observations were made in 1810.

<sup>2</sup> *Webster in Edin. Phil. Jour.* vi. 306 ; 1822.

<sup>3</sup> The specific gravity of the older and coarser varieties of the si-

Different stalactitic siliceous concretions are described by V. Buch as deposited by the vapour of boiling water on the walls and fissures of the crater of the volcano of Lancerote; and near Monte Vico, in Ischia, the fissures, through which the steam passes are often coated with a siliceous incrustation<sup>1</sup>. Similar phenomena are observed among the volcanic rocks of the Solfatara, and at Sta. Fiora in Tuscany.

Sometimes, however, silica in the gelatinous or flocculent state is deposited in the reservoirs of certain thermal waters, in countries which are not now the seat of active volcanism. This is the case with many of the waters of France, where siliceous beds are often alternate with, are subordinate to, or enter in more than ordinary proportion into the composition of, the travertino masses. At Mont d'Or the waters deposit an ochre, which, according to the analysis of M. Berthier, is largely impregnated with silica<sup>2</sup>. Braconnot has found a black substance, deposited by the waters of Luxueil, to contain half its weight of silica<sup>3</sup>. The hot springs of Poorgootha in India deposit a residuum which, according to Turner, contains 0.23 of silica<sup>4</sup>.

liceous sinter was 2.107; that of the white semiopalescent varieties 1.886; and of the delicate filamentous kinds 1.856. This last consisted in 100 parts of silica 83.65, and water 16.35; thus differing from the analogous deposits of Iceland and Ischia in the large quantity of water, and the want of alumina and lime.

<sup>1</sup> *Daubeny* on Volcanoes, p. 182.

<sup>2</sup> *Annales de Chim.* xix. 30. 100 parts of this sediment consisted of:

Silica,	.	.	.	.	11.6
Oxide of iron,	.	.	.	.	61.5
Carbonate of lime,	.	.	.	.	2.5
Water,	.	.	.	.	24.4

---

100.0

M. Berzelius has since found it to contain, in addition, phosphoric acid, in union with alumina, lime, and oxide of iron.

<sup>3</sup> *Annales de Chem. et Phys.* xviii. 221. It consisted of:

Silica,	.	.	.	.	1.00
Baryta,	.	.	.	.	0.09
Oxide of iron,	.	.	.	.	0.13
Peroxide of manganese,	.	.	.	.	0.70
Ulmene,	.	.	.	.	0.08

---

2.00

<sup>4</sup> *Brongniart*, *Tableau des Terrains*, 1829, p. 48.



In some instances even we find primitive and other highly siliceous rocks, become coated with a glossy encrustation, not dissimilar to some of the phenomena of hot springs, from simple exposure to the weather on the contact of atmospheric moisture. Dr Macculloch has noticed the graphic granite of the island of Rona, to be coated with a calcedony-like enamel, in situations much exposed to the weather, arising apparently from a partial solution of the silica in its composition. Similar crusts have been seen investing the granite of Rockall, and the sandstones of Jura and Schihallion. And Mr Caldcleugh has observed some beautiful siliceous stalactites, in the mountains near Rio Janeiro; they were situated at the junction of two beds of gneiss, and in a situation much exposed to the trickling of water down the bare sides of the hills, exposed to the full action of the rays of a tropical sun<sup>1</sup>.

In order to bring under one view the principal points of interest connected with the history of the siliceous deposits of springs, I shall here bestow a few words on the consideration of the agent which holds this highly insoluble earth in solution, although it more properly perhaps belongs to the head of the origin of the ingredients of mineral waters.

The silica of the Icelandic springs is associated with alumina, the muriate and sulphate of soda, sulphuretted hydrogen in small quantity, and caustic soda (See page 25, note). The late celebrated Dr Black considered the latter ingredient to be the medium by which the silica was dissolved, assisted, however, in its operation, by violent and long continued heat; in opposition to the opinion of Bergman, who ascribed this power entirely to the water, aided by excessive heat. Bergman, it is true, was not aware of the presence of soda, but, with all due respect to the opinion of the distinguished Scotch chemist, I imagine that the opinion of the former, is nevertheless the more probable, as well from the chemical facts stated by Black himself, and the natural processes

<sup>1</sup> Geological Transactions, series 2d, ii. 71.; 1829.

observed in other parts of the globe, as from the physical phenomena presented by an inspection of the springs in question.

In opposition to the objection of the proportion of alkali being too small to dissolve originally so large a quantity of silica,—it being as  $13\frac{1}{2} : 100$  in the Rycum waters, and as  $16 : 100$  in the Geyser. Black merely brings the hypothetical assumption of a larger quantity of alkali having been enlisted in the process in the interior of the earth, and that part of it has been subsequently neutralized by the contact of different acid vapours, &c. While, on the other hand, he stated the positive fact, that if silica be dissolved in water by means of an alkaline salt, although the latter be afterwards saturated with an acid, no separation of the earth will follow if the quantity of water be sufficiently large,—shewing that silica, in certain circumstances at least, may be held in solution by water, independently of the power of an alkali. Besides, we see that silica is dissolved by many thermal waters, where no uncombined alkali is present. When artificial compounds are formed of silica and soda, in the proportions in which they exist in the Iceland springs, although cold water has no power to dissolve them, they are acted on by boiling water by length of time. It is well known that even cold water or the common moisture of the earth, acts on glass in the course of years or ages; and the repeated distillation of water exercises a slow abrasion upon glass retorts. Silica in its perfect state of aggregation is quite insoluble in water, in the proper sense of the term. But Berzelius has shewn that when in its nascent state it is in contact with that fluid, it is dissolved in large quantity, and on evaporating the solution slowly, a bulky gelatinous substance is obtained,—the hydrate of silica.

What we here perform in our laboratories is the work of nature in the formation of many of her mineral products, such as the whole tribe of opals, which is carried on almost under our very eyes. M. Beudant has seen in the country of Kremnitz in Hungary, veins and nodules

of jasper opal, which, when first taken out of the rocks, were quite soft and unctuous like steatite, and sometimes presented all the characters of an artificial gelatinous hydrate of silica a little dried, and these from situations deep imbedded in the mass of the semivitreous trachytes, where they were quite protected from the action of the weather. On being exposed to the air, these opals contracted and became fissured in all directions, exactly like the artificial hydrates. Even the opal miners know very well how to distinguish these nascent opals, which they distinguish by the epithet of *unripe*<sup>1</sup>. In this case the silica has evidently been deposited in its present situation by water impregnated with siliceous matter.

If, to this we add the peculiar manner in which the Geysers make their exit to the surface, not in a continued stream, but in jets or explosions to a height of at times 130 feet, with a temperature never below 212° F.;—and that their eruption is preceded by many of the phenomena of an earthquake on a small scale, such as rumbling noises in the interior of the earth, a convulsive heaving of the ground, with the projection of stones to a great height in the air;—all indications of the escape of an elastic fluid from a state of great compression; we shall become convinced that the solubility of flint is in this case much rather to be ascribed to the agency of steam under great compression, and consequently at a high temperature, than to an inconsiderable quantity of caustic soda<sup>2</sup>.

III. *Mechanical (aluminous ?) deposits of hot springs.* Under this head I include those rocky masses which owe their formation to the disintegrating effects of certain thermal waters on previously existing lavas, wackes, &c., reducing them to a loose incoherent consistence, and

<sup>1</sup> *Beudant*, Voyage, i. 391, 496; iii. 489, 501.

<sup>2</sup> Some idea of the prodigious state of compression of the steam in the subterranean reservoir of the Geyser may be formed from the fact stated by Mackenzie, that the column of vapour discharged from the pipe of the New Geyser remains perpendicular to the height of seventy feet, although a brisk gale of wind should be blowing against it.



in some cases to a sort of mud, which may or may not be transported to a distance from its original situation.

I believe that in this definition we have the simplest explanation of the true nature of those singular rocks, which have been more or less alluded to by every traveller who has visited Iceland, and are described by some as occupying a very prominent place among the formations of this island. The attention of naturalists was first called to these singular masses by Olafsen and Povelsen, about the middle of last century, since which time they have been illustrated by the observations of Stanley and Menge; but I believe we are chiefly indebted to correct and rational ideas of their true nature to the short but luminous exposition of Professor Jameson in the year 1820<sup>1</sup>. I am aware that doubts have been attempted to be thrown upon these observations, more perhaps from their dissimilarity to phenomena observable in countries which are destitute of the magnificent display of hot springs peculiar to Iceland, than from their discrepancy with the known course of Nature in other parts of the globe. For we have undoubtedly in the vast mud eruptions of many volcanoes, an instance of depositions, not very unlike the rocks in question.

These *volcanic-neptunian* rocks, as they have been happily denominated by Jameson, resemble in their external aspect many varieties of basalt, wacke, amygdaloid with crystals of calcareous spar, tufa; and when they are infiltrated with siliceous matter, even some of the modifications of the semivitreous true igneous rocks. They are brought from the interior of the earth, partly in a state of mud, partly in a state of solution, and are deposited over flat or hilly tracts of country, where they gradually harden, sometimes assume a semicrystalline aspect, and take on their different permanent characters. The transition can be gradually traced from the mud still held in suspension by the hot springs, to the densest and most compact rocks. Thus, Menge describes near Cape Rei-

<sup>1</sup> Edin. Phil. Jour. ii. 307. Account of Rocks formed by hot springs, &c.

kaness<sup>1</sup>, a boiling marsh, about 300 paces in circumference, composed of a muddy hot mass more or less mixed with sulphur, and of various colours, as blue, red, &c. Several hard positions of this muddy mixture, when cold, presented in the centre, all the characters of basaltic lava, but towards the surface gradually passed into indurated red or grey mud. All round the Rycum springs also, Stanley mentions that the heated soil is gradually changing into a clay beautifully variegated with blue, red and yellow. The ground in the vicinity consists of loose lavas broken and pounded together, several pieces of which remained quite unaltered, while the rest were reduced to a dust. The same author mentions, that round the Geysers, wherever the ground is penetrated by the steam of the springs, the fragments of lava are soon decomposed or changed into coloured clays. Mackenzie also mentions that the little hill at the bottom of which the Geyser bursts forth, contains many beds of clay from different fissures, in which steam rises, and which contain many small basins of boiling mud, tasting strongly of sulphate of alumina. The same author has also given a very interesting account of the sulphur mountains near Krisuwick,—great natural laboratories where sulphur, clay, mud, boiling mud-springs, and steam, seem to be incessantly exerting their forming and destroying influences. Olafsen and Povelsen mention that some of these *Boles*, as they call them, effervesce with acids; others contain imbedded crystals of iron-pyrites, occasionally sulphur, and have a sourish taste; a third class are impregnated with siliceous matter<sup>2</sup>.

The hot springs of the valley of Furnas in St Michael's, are surrounded by hills, which are composed of a clay of greater or less compactness, coloured by the oxide of iron, and intermixed with fragments of pumice and siliceous sinter. In the vicinity of the Caldeiras steam and hot water issue forth in all directions from fissures in this clay. Near the springs it loses all traces of vegetation, and its natural dark colour, becoming either quite

<sup>1</sup> Mineralogical Journey in Iceland, Edin. Phil. Journ. ii. 165.—*Reise durch Island*, 4°. 1774.

white, or variegated with red, brown or purple colours. The water of the boiling reservoirs, every where holds in suspension a large quantity of alumina, giving it a soapy feel; and sometimes this earth is the mineralizing material of the vegetable matter with which the water comes in contact. Some of the stalactites formed by these springs are also, we are informed, chiefly composed of alumina. Near the largest *Caldeira*, is a hillock about 50 feet high, entirely formed of alternations of siliceous sinter and clay, containing fragments of petrified grass, reeds and ferns. Many years ago part of this hill fell in, when it appeared to be merely a dome-like vault covering a vast cavern of boiling water, which ejected great quantities of mud and stones. In other parts of this singular island a sort of breccia is formed of fragments of siliceous sinter, obsidian, pumice, and scoriæ, united by a siliceous cement. The daily formation of this breccia is still seen going on by the agency of the hot springs.

We are certainly not at liberty to set aside these facts which rest upon the authority of so many observers of acknowledged accuracy. Besides, they are not without their analogies in other parts of the world. There are on record many instances of torrents of hot water, flowing from the craters or sides of volcanoes, which, when collected into hollows or spread over plains, deposit various earthy matters, which assume the characters of rocks. These are most remarkable in Etna and the enormous volcanic cones of Cotopaxi, Pinchincha, Tungurahua. This *Moya* is further interesting, as it often contains traces of glassy felspar, and imbedded portions of a fibrous substance resembling pumice, thus approaching in its characters to some trachytes and porphyries. The different air or mud volcanoes, as they are called, present phenomena entirely of a similar description. Of these, the most interesting with which we are acquainted, are those of Macalouba in Sicily; the Salses near Modena; the Island of Taman in the Crimea, described by Pallas; Turbaco in the province of Carthagena in South America, described by Humboldt; in Trinidad, and in Java. In all these cases the cones from which the gase-



ous matters and liquid mud are discharged, consist of hardened mud or clay, which it is not improbable possess characters resembling the moya of South America, and the thermal rocks of Iceland, although in this case the water is cold.

In Iceland, these rocks, which owe their formation or at least their present form of aggregation, to the agency of hot springs, seem to form masses of great extent, particularly in the whole volcanic region, extending from the Guldbringe Syssel on the west, to Myvatn on the east. It is less common in the southern part of the island; where, however, in the Borgarfjord district, we find the mountain of Baula composed of a rock possessing the same general characters with those above mentioned, as found around the presently existing hot springs.

Even with regard to the more peaceful mineral waters of Europe, we often find a decomposing effect exerted on the rock in the vicinity of the spring, which, though not modifying to the extent of the former, the physiognomy of the earth's surface, is evidently of nearly the same nature. The trachyte of the hill of Budos in Transylvania, is converted into alum-stone by the action of the hot sulphureous vapours on the constituents of the rock. And in Volcano, one of the Lipari Islands, the sulphuretted hydrogen, which contains a minute proportion of muriatic acid, penetrates the trachytic rock, and forms large quantities of alum and other sulphuric salts. The waters of St Nectaire exercise a decomposing influence on the granite from which they issue, in different points, which is much softer than at some distance from the springs. In the valley of Furnas, wherever the rocks (lava, trachyte, and pumice) are exposed to the contact of steam and acid vapours, their colours are quite lost, being white, and they become soft and sometimes quite argillaceous.

Stiffert has also remarked, that very frequently, in the vicinity of some of the mineral waters of Nassau, the rock is changed into a soft clayey mass, or reduced to an accumulation of sandy particles<sup>1</sup>. I call the attention of

<sup>1</sup> Geognost. Beschreib. p. 585.

my readers to this fact, without asserting positively, that it is effected by the action of the mineral waters. It may be an appearance analogous to the faults of miners. Farther observations are requisite to determine its true nature ; meanwhile, its frequent occurrence in the vicinity of these springs called for a notice in this place. This appearance is not owing to the decomposing agency of the atmosphere, for it is found at considerable depths, and imbedded in the midst of perfectly solid rock. It is very distinct in a hill composed of amygdaloid, opposite the springs of Fachingen, on the left bank of the Lahn, where the surrounding solid rock is changed into a soft clay, which acts as a conductor of the percolating moisture to the surface of the earth ; the water, however, has no mineral taste. A loose sandy state of the quartz-rock was observed in digging in the vicinity of the Wiesbad springs. A similar loose clayey state of the talcose schist was observed near the waters of Cronberg, Soden, and Schlangenbad, and upon removing from the springs the strata resumed their natural consistence and aspect<sup>1</sup>.

Thus far we can advance with safety, there being nothing repugnant to the laws of nature, and from the concurrent testimony of so many eye-witnesses of the facts which they describe. But we must certainly pause when it is advanced that we actually see nature in the act of forming sulphur, silica, lime, oxide of iron, iron-pyrites. Nature has not admitted man to be a witness of her secret operations in the formation of the elements, or even the proximate compounds of bodies. He can only be the historian of their mutual reaction on each other, subsequent to their formation, and of the modifications that they induce in the physiognomy of this globe that we inhabit. And does not the following assertion, if it has

<sup>1</sup> In regard to this state of the rock, Stiff proposes the query : Can it be owing to galvanic agency ? Or is it ascribable to the ascent of acid vapours through fissures diminishing the cohesion of the rock, whose effects were afterwards terminated by the subsequent closing of the fissure ? He connects this with his theory of the origin of mineral waters, by the volatilization and sublimation of different mineral matters, from the common focus in the interior of the earth, of mineral springs and volcanic phenomena.

any signification at all, savour somewhat of the long ago exploded notions of the alchemists? "We cannot maintain that the silica in these hot springs is derived from a quartzose solution, because quartz is one of the rarest minerals in Iceland. The siliceous sinter, with all the other substances afforded by the siliceous water, viz. sulphur, gypsum, alum, bole, &c., disappear as soon as the water cools, and the residuum is trap-porphry, basalt, and even amygdaloid."—(Menge.) Nor can it be admitted in the present state of our knowledge, that *true* obsidian is ever a product of thermal waters.

These are the most important of the substances which result from the forming effects of mineral waters. We have a few instances of the natural deposition of sulphur *via humida*, where this combustible was held in solution by the hydrogen gas. The quantity, however, precipitated is always very insignificant. The principal examples are the thermal waters of Aachen, Aix in Savoy, Balaruc in France, and the cold springs of Engghien near Paris. What was called the Bath sulphur in this country has been sufficiently shewn by Dr Lucas, to be merely a vegetable substance of the nature of a conferva.

The bituminous matters discharged from the earth in different parts of the world belong to an order of springs distinct from those properly denominated mineral waters, and enter into the series of the ordinary geological formations.

Before concluding this chapter, I may be allowed to subjoin a reflection, which doubtless has occurred to the reader more than once on the perusal of the preceding pages, and forms a proper appendix to the consideration of the rock deposits of mineral waters. It is evident, from the prodigious mass even of their undoubted chemical and mechanical deposits, and still more if we include in this list those comparatively recent geological formations, which many distinguished geologists consider as chiefly indebted for their origin to processes very analogous to those of our present hot or cold springs, although on a scale of much greater magnitude,—that



we must adopt one of two suppositions. Either these springs must have flowed in their present state for an immense period of time, and must be of a date much more ancient than that commonly assigned by historical documents to the present state of things on the surface of the globe; or that they must have formerly been much more abundant, and have played a much more conspicuous part than now in modifying the features of the earth's surface. The first of these suppositions is hardly admissible, as, from the actual increase of these deposits being so very slow, it would require a period of time for the production of these tufaceous masses which is hardly conceivable, and would be quite at variance with the march of nature, as indicated not only by historical, but also geological, records. The second supposition is well fitted to furnish materials for the most profound meditations; but, confessedly, we possess but few data for forming a tolerable idea of the regulating laws of the mineral waters of these epochs, which, although anterior to written monuments, are comparatively recent in the annals of this world's history.

Whatever analogy there may be between the deposits of springs, and those fresh water tuffs and limestones which have been alluded to above as still forming at the bottom of lakes and on the sea shore, and which some consider as the modern counterparts of the tertiary, marine, and fresh-water formations,—for, although some of these recent formations are partly owing to the mechanical precipitation and cementation of earthy particles, others are undoubtedly due to a crystalline sediment,—there is this important difference, that here the deposit is tranquilly going on at the bottom of marshes, or in situations secluded from the contact of the atmosphere, while most of the tufas of springs result from the free disengagement into the air of the carbonic acid, by means of which they are enabled to hold the carbonate of lime in solution. From which it results, that the deposits of marshes and other analogous rocks resemble much more closely the ancient geological formations; and, indeed, in their mineralogical structure they approach much

nearer the tertiary rocks than even the oldest and most solid of the tufas of springs.

In texture and mode of formation, although not in chemical composition, the mechanical rocks of the Icelandic springs, and the moya of volcanoes, approach much nearer these deposits than the travertinos of Italy. The great tertiary silex formations, however, are very closely allied in texture and composition to the siliceous tufas of Iceland. It would, however, be foreign to the object of this Essay to trace out these analogies with greater minuteness of detail.

Here, then, no less than by the inferences which I have attempted to draw at p. 206, an important and interesting parallelism exists between the phenomena of volcanoes and of mineral waters. Volcanism is no longer now the formidable and gigantic agent which it has been at the epoch of the formation of the trachytes and basalts, which cover so large a space of the earth's surface; it seems to have undergone a progressive diminution in its energy, and in the scale on which it is carried on, till it has finally attained the comparatively moderate degree of violence which at present characterises it. But are we to consider the phenomena of volcanic mineral springs divisible into periods, following more or less closely the developments of volcanic action? Here the cautious philosopher must pause. Facts are still wanting for the affirmation or the negation of so weighty a problem.

## CHAPTER III.

## ORIGIN OF MINERAL AND THERMAL SPRINGS.

IT may be supposed by many that, on entering on this branch of the doctrine of mineral waters, we are launching into the boundless ocean of conjecture,—that we are attempting to judge of the phenomena and operations going on in the interior of the earth from the few and scattered observations that we are able to make here and there on its surface. But if we are entering upon a dark and unexplored region, we are fortunately not entirely without a guide. Active volcanism furnishes us with facts of a very singular description, which we employ with safety in reasoning regarding thermal waters, and a very extensive tribe of cold mineral springs. The origin of these is perhaps no more dubious, although they are carried on on a scale of less magnitude, and accompanied by less magnificent displays of the energy of nature. The light which modern Chemistry and Geognosy have afforded in the explanation of volcanic phenomena and the chemical constitution of mineral waters, has not been without its influence in facilitating our researches into the origin of the latter.

Independently of these considerations, others present themselves of not less weight in inviting us to the inquiry. Some persons praise the collection of facts, but immediately (on Geology more especially) start when any general views are founded on them, which can alone confer any interest on facts, and for which alone facts are useful at all ;—as if here alone in the sciences we were continually to be recording the dry detail of observations, important no doubt in themselves, but which are yet merely the steps by which we may ascend to the



great causes of natural phenomena. We are sure that, of whatever influence on the workings in the interior of the earth is the enormous disproportion of the four conditions of heat, pressure, mass, and time, to what we can command in our experiments, yet that no operation runs counter to the known physical laws which we are accustomed to contemplate, and that no substance exists which can influence the processes carried on there, in such a way as to render nugatory all our chemical knowledge, when applied to the phenomena of springs. Besides, even if we could never hope to arrive at the true secret of their origin, it is still important to shew how they may be produced: this satisfies the mind, and is the best antidote to that indolent philosophy which either rests satisfied with its ignorance, or refers to a miracle those natural appearances which it is unable to explain.

Indeed, there is scarcely a subject which is fitted to excite a more lively interest than the origin of mineral waters,—of those inexhaustible springs which for hundreds and thousands of years have poured forth such enormous quantities of saline and other substances, without any perceptible diminution of their temperature, quantity, or degree of mineral impregnation. The inquiry is attended doubtless with great difficulty; but this should only render it more attractive, as requiring more continued and rigorous attention. But this very circumstance also affords greater scope for the fancy. It cannot, then, be surprising that in all ages this has been a favourite topic for the speculations of naturalists, chemists, physicians, philosophers, and even of theologians. Although, however, I would urge a more bold and unhesitating inquiry into the secret connections of many obscure physical phenomena, let it not be supposed that by this I mean to sanction the formation of hasty conclusions, desert for a moment the rigid laws of inductive philosophy, or give undue weight to facts which may be really unimportant. Nor ought the imagination to be allowed to gain the ascendancy over reason, which would inevitably lead us into hypotheses, if not altogether absurd, not less premature than those which cha-

racterize the speculations of many of the philosophers of Germany ; for, according to the advice of a late eminent philosopher, “ however active and brilliant the imagination may be in seeking analogies, it should be entirely guided by the judgment in applying them<sup>1</sup>.”

In the two preceding chapters, I have endeavoured to give as brief and accurate a summary as I possibly could of the positive facts which we possess on the history of mineral and thermal water. It may perhaps appear presumptuous in me to discuss the origin of these springs, after the many distinguished geologists, chemists, and mathematicians, who have applied the resources of their respective sciences to the elucidation of the subject. But my present exposition would be incomplete without it, and if we should arrive at no demonstrative explanation of their phenomena, the inquiry is well fitted to shew us the extent of the relations of mineral waters, and their intimate connection with the general physics of the earth ; and to redeem the science from the aspersions of charlatanry and empiricism which, in our own country at least, has been too often attempted to be thrown upon it, for what reasons I will not here stop to specify.

I shall first, then, give a short account of the principal theories which have been advanced to explain the origin of mineral waters. Although it is not improbable that the temperature of hot springs, and the nature of many of the ingredients of mineral waters in general, are essentially connected together, so that an inquiry into the origin of the warmth of springs will involve many of our ideas regarding the sources of the foreign substances which impregnate them ; still I conceive that it will conduce to greater clearness if we analyze the problem to its ultimate elements, and consider separately the distinct processes which we may conceive Nature to have followed either successively or simultaneously in their elaboration ; for it is not improbable that much of the obscurity and contrariety which is observable in

<sup>1</sup> *Sir H. Davy's Last Days of a Philosopher.*

many reasonings upon the origin of springs may be traced to the confounding together totally different operations. I shall, therefore, consider,—1. The origin of the water of mineral and thermal springs—of the menstruum which, ere it appears at the surface of the earth in this form, acquires such diversified properties ; 2. The source from which this water derives its elevated temperature in the case of thermal waters, which will lead to some remarks on the general causes of the permanent temperature of all perennial springs ; and, 3. The source from whence this water acquires its various mineral ingredients.

## SECTION I.

### THEORIES WHICH HAVE BEEN PROPOSED TO EXPLAIN THE ORIGIN OF MINERAL AND THERMAL SPRINGS.

FORMERLY a knowledge of the mode of formation of mineral waters was considered a subject of such importance, that no labour or expense was spared in order to obtain it. It was endeavoured, by the actual sinking of shafts, to arrive at their secret laboratories. We are informed<sup>1</sup> that Henri de Rochas, about the beginning of the seventeenth century, resorted to this method of inquiry, in regard to some of the warm springs of Switzerland ; and, at the commencement of the eighteenth, Schuster attempted to dig down to the sources of a chalybeate water. This method, as might be expected, leading to no conclusive results, was very soon entirely abandoned.

It is curious that one of the earliest suppositions to account for the heat of springs, is that to which geologists have recurred at last after the conflicting opinions of several centuries,—that which derives them from subterranean fires. Indeed the mind of man would naturally connect the discharge of so large a quantity of

<sup>1</sup> Osann Darstellung, p. 104.



fluid, at such a high temperature as many springs possess, with the most palpable evidence of central fires, presented by volcanic activity. This was the opinion of Descartes, Halley, Leibnitz, Mairan, and Buffon. It was subsequently for a time laid dormant by the prevalence of the Neptunian cosmogony.

It was only when men began to be warped from the dictates of sober reason and simple views, by the eagerness to explain every thing otherwise inexplicable upon their newly acquired and somewhat confused chemical notions, that they had recourse to the spontaneous combustion of iron-pyrites,—a theory which maintained its ground for a very long period. It was founded on, or at least it first derived plausibility from, the well known experiments of Newton<sup>1</sup> and Lemery<sup>2</sup>, that, by the coming in contact of iron-filings and sulphur, accompanied with moisture, a considerable degree of heat is generated, and in time phenomena are produced supposed very much to resemble volcanoes in miniature. It is, however, but justice to the latter author to state, that he considered it possible that certain mineral waters derived their heat from what he calls “une chaux naturelle,” which was a rock calcined by subterranean fires. This natural fermentation of iron-pyrites by the contact of moisture was successively the opinion of Blondel<sup>3</sup>,

<sup>1</sup> Optic, p. 354.

<sup>2</sup> Explication Physique et Chymique des Feux souterrains, des Tréblemens de Terre, des Ouragans, des Eclairs et de Tonnerre. Mem. de l'Acad. R. des Sciences pour 1700. 12o, Amstelod. 1734, p. 140. It may interest the reader to have the experiment in his own words: “J’ai mis en été cinquante livres du meme melange (equal parts of filings of iron and powdered sulphur), dans un grand pot, et j’ai placé le pot dans un creux que j’avois fait faire en terre à la campagne, je l’ai couvert d’un linge et ensuite de terre à la hauteur d’environ un pied: j’ai aperçu huit ou neuf heures apres, que la terre se gonflait, s’échauffait et se crevassoit, puis il en est sorti des vapeurs soufreuses et chaudes, et ensuite quelques flammes, qui ont elargi les ouvertures et qui ont repandu autour du lieu un poudre jaune et noire: la terre à demeuré un long temps chaude, je l’ai levée apres qu’elle a été refroidie je n’ai trouve dans le pot qu’une poudre noire et pesante; c’est la limaille de fer depouillée d’une partie de son soufre.”

<sup>3</sup> Descriptio Thermarum Aquisgranensium, 1685; cap. ii. p. 22-56.

Lister<sup>1</sup>, Berger<sup>2</sup>, Henkel<sup>3</sup>, and many others. One of the last who applied it to an individual spring is Dr Becher<sup>4</sup>, who supposes, in regard to the Karlsbad waters, that water holding in solution the muriate of soda flows over a burning bed of iron-pyrites, the sulphuric acid of which converts the muriate into the sulphate of soda. He supported his supposition on the circumstance of a hornstone bed, containing much disseminated iron pyrites, having been found traversing the granite from which the waters of the Mühlbrunn issues. It was also adduced as a confirmatory fact, that coal-mines are often ignited by the intestine heat produced from the spontaneous decomposition of the iron pyrites, mixed with the rubbish in old workings and deserted galleries. It is certainly true that very rarely do we find a burning bed of pyrites unconnected with coal. We are, however, informed by Berzelius, that the mass of pyrites which was inflamed in the mines of Fahlun towards the end of last century by wood, continued to burn for fourteen or fifteen years, during which period sulphureous acid vapours were constantly discharged through the fissures of the mountain. The combustion then ceased of itself in the midst of the immense mass of pyrites which constitutes the *Erzfeld* of Fahlun.

To this theory, however, as applicable to explain the origin of springs, may be opposed the following considerations :

1. Radiated pyrites alone, of the three species of iron pyrites with which we are acquainted, can be decomposed with sufficient rapidity for the disengagement of a high degree of heat. Even this species requires to be placed in a certain favourable combination of circumstances, which is very seldom met with in the interior of the earth, such as the presentation of a large surface of contact to the surrounding moisture, the supply of air and moisture in a due proportion, which, if either exceeded or diminished, decomposition will not ensue<sup>5</sup>.

<sup>1</sup> De fontibus medicatis Angliæ, 1684; cap. ix. p. 48.—<sup>2</sup> De Ther-  
mis Carolinis, 1709; cap. vi. p. 63, 72.—<sup>3</sup> Pyritologia, 1725, p. 62.—

<sup>4</sup> Karlsbad, 2d edit. 1789, p. 204.—<sup>5</sup> Cordier on Subterranean Tem-  
perature in Mem. du Museum d'Hist. Nat. 1827; and Edin. New  
Phil. Journ. vi. 42.

2. Even should the fact of decomposition be correct, it is insufficient to account for the phenomena observed. Iron-pyrites occurs in a quantity by no means adequate for the production of such extensive and general effects. These must, therefore, depend upon causes deeper seated, and more intimately connected with the constitution of our planet.

3. If springs, in their passage through the interior of the earth, derived their heat from this cause, they should much more frequently, indeed in almost all cases, contain sulphate of iron, or other ferruginous or sulphurous acid impregnations. This, on the contrary, is not found to be the case; the former of these compounds is found only in cold springs; and many hot springs exist in situations where no traces of pyrites can be found, and are destitute of the smallest traces of iron.

4. If they drew their origin from pyritic deposits, they should decrease both in temperature and quantity of foreign impregnation, as these strata become exhausted. On the contrary, it is more than probable that both these conditions have persisted unaltered for the long period of 2000 years, nay, in some cases, seem to be slowly on the increase, as at Karlsbad.

The cold springs of Cheltenham are a striking illustration of the change which they will inevitably experience when pyritic deposits are their probable sources. These mineral waters are strongest when first opened, and gradually decrease in strength, until it becomes necessary to sink new wells in order to obtain water of the requisite power<sup>1</sup>. Now they rise in a stratum of blue clay abounding in iron-pyrites, which reposes in the inferior oolite limestone.

5. It is inconsistent with the great magnitude of the discharge of water from many of them, and the impetuosity with which they issue to the surface.

It may be advanced, that, though iron-pyrites cannot be considered as the universal source of mineral and thermal springs, yet that, in many situations, to be de-

<sup>1</sup> Rees' Cyclopædia, Art. *Temperature*.



terminated by the inspection of the environs of the springs, they may be referred to it as a cause. The above considerations, however, are sufficient to shew that the decomposition of this mineral, spontaneous or otherwise, can *in no case* be viewed as the source of the heat of springs; and only in a very limited class of cold springs can any of the foreign ingredients be derived from it.

Another supposition was advanced by Klaproth<sup>1</sup>, which he supposed to be free from the objections that might be urged against the one just discussed,—that thermal waters were heated by the proximity or contact of immense beds of coal in a state of combustion, that reacted on iron-pyrites, limestone, and rock-salt deposits, which may be in a manner regarded as the raw materials out of which Nature elaborates all the diversified effects seen in these waters. The carbonic acid of the water was derived from the limestone by the action of the heat of the burning beds of coal, and, as it had no free escape, was forced to impregnate the water. The sulphate of soda of the Karlsbad water, for the explication of whose phenomena his hypothesis was more especially framed, arose from the muriate of soda brought by this water, the sulphuric acid being produced from the iron-pyrites set on fire by the coal, in the same way as the carbonic acid from the limestone. “It is not so easy,” says Klaproth, “to determine the method which Nature has employed to bring the free soda in contact with the Karlsbad water, for none of our chemical processes furnish any clew to its solution. Perhaps the long continued action of subterranean heat and watery vapour (*feuchten Dünste*) is alone sufficient to expel a portion of the muriatic acid from its combination with the soda.”

But this theory is liable to the same objection with the former, in being too partial and local a cause to account for such general effects. Although coal beds are found in the vicinity of a few thermal waters, such as Karlsbad, Aachen, Bath, Baden in Austria, Wiesbaden,

<sup>1</sup> Beiträge, i. 346.

&c.; in the first of these situations alone is it in a state of combustion, where, on the north bank of the Eger, there are beds known to have been burning ever since the year 1347, in which the Karlsbad waters were discovered, thus for a period of 480 years. But the position of these beds, as indicated by the products of their combustion, the porcelain jasper, burnt clay, and earth slag, which are scattered over the plain, is such that they can have no connection with the Karlsbad springs. In the Böhmerwaldgebirge, to which these waters belong, no secondary formations at all are found, nor traces of coal on its combustion. These are confined to the opposite side of the valley of the Eger, and are most abundant near the town of that name. Although the combustion of a coal bed may last for a very long period, even for centuries, as in this case, it must terminate at last. But the warmth of the Karlsbad water is evidently of a date far anterior to its first discovery; for the tufaceous vault of the Sprudel kettle forms for a considerable space the immediate bed of the river Teipel. This covering to the boiling reservoir must, therefore, have been formed before the valley in which Karlsbad is placed was excavated, which ascends to an epoch much older than history.

Coal, as far as geological investigations have hitherto extended, is almost entirely confined to the great class of secondary rocks; for, although carbon in a purer and more crystallized form is met with in older formations, its quantity is too inconsiderable to be for a moment regarded in the present instance. Now, I trust that it has been shewn satisfactorily, in the preceding chapter, that warm springs and the large class of acidulous and alkaline waters are almost invariably found to emerge from mountain chains, or at least close to their immediate base; that these ridges are in such cases always formed of granitic, trachytic, basaltic rocks, or they are of undeniable volcanic origin. But coal is seldom found in such a position in considerable quantity. Its most extensive deposits occur in great basin-shaped hollows of the earth's surface, or in those extensive plains from

which these springs very seldom arise. Coal, too, does not seem in most cases to be seated at a very great depth beneath the general surface of the earth, at which we must certainly suppose the focus of the operations to be placed which give origin to these springs, whatever theory we may be inclined to adopt. What shall we say, for example, to the Island of Java, or the Geysers of Iceland? Should this, however, be supposed an extreme case, what shall we say to those numerous warm and acidulous springs which issue forth from the Alps of Switzerland, the lofty heights of the Andes, and even from the Himalayahs, where no coal whatever exists?

Such are a few of the geognostical reasons which I conceive to be incompatible with the origin of warm springs from pseudo-volcanism.

It is not less incompatible with the laws of chemistry. Wherever the combustion of coal is going on, especially to such an extent as this hypothesis presupposes, there must be some exit for the enormous quantity of carbonic acid, carburetted hydrogen, and other elastic vapours, which will be necessarily disengaged. The hot vapour which, in such situations, issues forth through fissures in the earth, deposits on the cold bodies with which it comes in contact, muriate and sulphate of ammonia, sulphur, and many other substances, while the carbonic acid escapes into the air. None of these phenomena are observed near warm springs, and they are entirely destitute of the salts of ammonia, or of empyreumatic impregnations; and the residuum of their evaporation never indicates any thing but the minutest proportion of combustible matters. Carbonic acid is a very frequent, almost a universal, ingredient in these springs. But it is not at all probable that this gas can be formed from its elements by the union of carbon from the burning coal with oxygen. From whence can this oxygen be derived? In atmospheric air, its most likely source, it is diluted with four times its volume of azote, which must of course escape, should the oxygen unite with the carbon. But azote has been nowhere found in such



enormous quantities as this would suppose: neither can it enter into other combinations in the interior of the earth, so as to form, for example, nitrous acid, or ammoniacal gas. For we would only, in the former case, increase the demand for oxygen, and, consequently, the quantity of azote to be disposed of. To account for the formation of hydrogen will lead us into an endless labyrinth of conjecture, without any prospect of coming to a termination, and at every step of which difficulties would multiply on every side. The real origin of carbonic acid will come to be examined afterwards: it was enough here to shew that it cannot be derived from the combustion of strata of coal, and that its abundance cannot therefore be held as an argument for deriving hot or acidulous springs from this source.

Another hypothesis was advanced, especially to account for the heat of springs, deducing it from the nature of their impregnating minerals, a cause residing within themselves<sup>1</sup>. But we have only to regard for a moment the variety of those ingredients, and their little proportion to the heat of different springs, to see at once the fallacy of this supposition. The quantity of mineral matter in many hot waters is so very small, that, on cooling, they can hardly be distinguished by their taste and other sensible properties from the purest springs. It is true that sulphur, soda, and common salt, do occur in many thermal waters, but then many also exist without a trace of these substances. And how many cold springs do not owe their peculiar properties to these fancied generations of heat?

Döbereiner has more recently supposed that the elevated temperature of springs can be explained by a law analogous to the diminution of temperature as we ascend in the atmosphere<sup>2</sup>. That, as in the higher regions of the air, the lower temperature is explained by its rarefaction, and consequently increased capacity for caloric. The reverse of this must take place in the interior of the earth, and, by this increased density of the air, he en-

<sup>1</sup> *Rutty's Synopsis*, p. 592.—<sup>2</sup> *Chem. Constit. d. Min. Wass.* 9. 23.

deavours to explain the heat of springs. But if this were the case, the degree of their temperature ought to be proportioned to their elevation above the level of the sea. On the contrary, we find hot springs at considerable heights in the Alps of Switzerland, the Andes, and the Himalayahs.

Galvanism, that powerful agent which, by the electrochemical discoveries of late years, has been observed to exert an extensive influence upon the changes and motions going on in the physical world, was naturally extended to explain the mysterious origin of springs. The germ of this hypothesis may be found in some of the speculations of Schelling. But Steffens was the first who formally applied it to explain the phenomena of springs<sup>1</sup>. He supposed that the different strata of the earth's crust performed the part of a vast voltaic pile, with regard to the subterranean mineralization of waters, certain classes of which accumulated round the positive, and others round the negative, pole. This theory was at first adopted by several naturalists, such as Wurzer<sup>2</sup>, Harless<sup>3</sup>, Ebel<sup>4</sup>, &c. Its untenable nature, however, has been amply shewn by Gilbert<sup>5</sup>, Kastner<sup>6</sup>, and Bischof<sup>7</sup>. An ingenious modification of the original theory has been proposed by Reuss of Moscow, to account, among other phenomena, for the flow of water from springs in situations too high for the water to reach by pressure from another source<sup>8</sup>. To this power he gives the term

<sup>1</sup> Geognost. Geolog. Aufsätze, 1810, p. 309.—<sup>2</sup> Nenndorff's Schwefelq. p. 37.—<sup>3</sup> Jahrbücher der Medicin u. Chirurg. viii. pt. 3, p. 104.—<sup>4</sup> Über den Bau der Erde in der Alpengebirge, pt. ii. 369.—<sup>5</sup> Annalen der Physik, lxiv. 153.—<sup>6</sup> Rullmann's Wiesbaden, p. 139.—<sup>7</sup> Vulkanische Mineralquellen, p. 319.

<sup>8</sup> Commentat. Soc. Physico-Med. Mosquensis, ii. 327, 1817; and Edin Med. and Surg. Journal, xxx. 222.

The following extract will give an idea of the author's reasoning: "Omnes enim (mineral waters) vel illa elementa vehunt quæ inter analysin electricam ad polum negativum feruntur, qualia sunt aër hydrogenio-sulphureus, soda, calx, magnesia, vel illa quæ ad positivum polum exsurgunt, quorum præcipua sunt acidum carbonicum et oxidum ferreum. Quod si igitur acidulas ferratas pro poli positivi, progenie aquas sulphuratas vero et alcalinas pro negativi poli sobole habere licet, intelligitur cur fere omnes aquæ minerales ad alterutrum genus referri possint, cur plerumque haud procul ab eo loco, ubi alterutra aqua acidula nempe vel sulphurata scaturit,

of *Vis Electricitatis Hydragoga*. It is founded upon the fact, that he found galvanism to possess the power of moving water through certain porous bodies, from the positive to the negative pole, independently of its power of separating this fluid into its constituent elements. This decomposition, however, always went on as usual.

Insurmountable difficulties, however, attend the extension of the theory of galvanism in any form to explain the phenomena of mineral waters.

In the first place, we have no means of knowing the relative electricities of the sources from whence springs are derived, and of the external atmosphere. With regard to the latter, at least, its electricity is in a state of continual change, both as to kind and quantity. At one time it is positive, at another negative; sometimes highly charged with it, at another time scarcely perceptible by the most delicate instruments; and yet none of these changes are known to influence in any way the impregnation of mineral springs.

We certainly find in the crust of the earth a series or succession of rocky strata; but in order that these should perform the part of a gigantic voltaic pile, they ought to succeed one another in a regular order of alternation, which is not found to be the case. It has, however, been maintained, that, although no such order has been yet detected by geognostic observations, galvanic mineral springs may be formed by simply the contact of a single pair of plates of two different strata. In this case these strata must be in contact, and surrounded by the substances to be acted on in a moist condition, a state of things which is certainly possible, but far from probable,

etiam altera reperiatur. Exemplo sunt ad Caucasum thermæ sulphureæ Constantinæ, quibus respondent acidulæ Narzanæ, in Bohemia, thermæ Carolinæ cum acidulis Egranis, in Wurtemburgia thermæ Ferinæ (Wildbad) cum acidulis Deinacensibus, multæque aliæ . . . . . Thermas plerasque pro poli negativi progenie censendas esse puto, primo quoniam hæ plerumque negativis elementis: sulphure, hydrogenio alcalibus materia resinosa vel bituminosa prægnant, deinde quia thermis quæ talibus elementis carent, tamen similis virtus medica inhabitat, unde colligi posse videtur perfectiori analysi chemica etiam in illis aliquando negativi quid detectum iri."



in the interior of the earth. But a capital objection to even this limitation of the theory is, that all experiments have hitherto failed to detect any electro-chemical habitudes between two different rocks thus brought into mutual contact.

Lastly, and this is the most powerful objection against galvanic agency. Mineral springs are not pure water; they are solutions of alkaline, earthy and metallic salts, the acids and bases of which possess directly opposite electric habitudes, so that, if they were the products of opposite poles of this immense galvanic apparatus, they ought to be at one time acid, at another alkaline, and these states should alternate with each other, or we should always find the acids forming one class of mineral waters, and their bases another. Relations such as these are never observed; on the contrary, uniformity of impregnation for a great length of years is one of their most striking features.

The last class of hypotheses which I purpose noticing is of such extravagant a nature, that, to the British reader at least, it carries along with it its own refutation. I could not, however, in justice, omit it in giving a summary of the theories of mineral waters. That which considers them as the products of some peculiar forces of our planet, the *qualitates occultæ* of the ancients, a sort of combination of electro-chemical, galvanico-chemical, organo-chemical, and magnetical processes. These theories regarding the creative energies of the earth, which evidently drew their origin from the times of the Greek philosophy (the ζῶον ἐμψυχον of Plato)<sup>1</sup>, and were afterwards adopted by Paracelsus, Van Helmont, and Kircher, have been more lately revived in Germany by Harless<sup>2</sup> and Keferstein<sup>3</sup>. The *ne plus ultra* of these hypotheses is certainly that which has been advanced by the last of these philosophers, who conceives that springs are living productions,—the lungs of the earth!

<sup>1</sup> Platonis Timæus, Oper. recens. Ficini, fol. 1602, p. 1048. l. 8.

<sup>2</sup> Jahrbucher der Teutschen Medicin, viii. pt. 3. p. 96.—<sup>3</sup> Teutschland Geognost. Geolog. v. 1-138.

which absorbs atmospheric air and oxygen, and exhales deoxidated air and water.

Such is a brief outline of the principal theories which have been proposed by naturalists to account for the appearances presented chiefly by thermal and acidulous springs, until the extension of the boundaries of geographical, geognostical, and chemical knowledge, taught them to look for causes deeper seated, and of more general application. For, notwithstanding the diversity which exists among them in regard to magnitude, temperature, chemical impregnation, altitude above the level of the sea, and position of the earth's surface; all the aspects under which we have yet contemplated their phenomena, and the insensible transitions which link them together into an almost uninterrupted chain in very different situations, only lead to the inevitable conclusion that, primarily, they are all derived from the same source, although modified by their subsequent course. Here, as in all the other departments of Nature, a closer inspection will only reveal to us the magnificent uniformity so conspicuous in all the parts of the great cosmical system.

## SECTION II.

### ORIGIN OF THE WATER OF MINERAL SPRINGS.

THE water of all springs, of whatever description, must be derived from one or more of the following sources :—

1. From the waters of the atmosphere which, after sinking to a certain depth, reappear on the surface of the earth.

2. From the focus of volcanic activity.

3. From the great mass of the ocean or other large collections of salt water.

4. From large subterranean reservoirs of this fluid.

It cannot be supposed to be in any description of springs formed by the union of its distinct elements, oxygen and hydrogen gases, which must exist for that purpose in a volume, and in forms, of which we have no conception.

It is extremely improbable, however, that the last of these sources holds any important share in the supply of these inexhaustible sources of subterranean moisture, principally on account of the two following circumstances: the known mean density of the earth, and the extensive distribution of a very large proportion of a peculiar class of mineral waters, the thermal and acidulous, which possess many relations in common, a circumstance which would go far to shew that they derive their greater supply of water from the same common source. The experiments and calculations of Maskelyne and Cavendish assign to our globe a specific gravity of no less than 4.9 times that of water, being fully one-third more than the mean density of its rocky crust. On this ground alone, therefore, such subterranean reservoirs cannot exist to any great extent. The second fact, again, would force us to view these reservoirs to be both seated at a very great depth, and to be of enormous magnitude, which we have just seen to be incompatible with the former consideration, unless, indeed, we should maintain the existence of a variety of such collections of water seated at convenient distances from one another, to maintain the supply of those springs in their immediate vicinity. But this is too palpable an invention of the fancy to deserve farther consideration: besides, the numerous evidences of a central heat entirely preclude the possibility of water maintaining its fluidity within the range of its influence.

The other three sources of the water of springs are very far from operating singly in the production at least of the greater number of mineral waters. But it is difficult, perhaps even impossible, to determine the share which ought to be assigned to each in particular as they pass into one another by insensible degrees. I shall there-



fore endeavour to examine the manner in which each of them operates, and the particular tribes of mineral springs which they may be considered chiefly to influence.

It has been commonly admitted that the mass of aqueous fluid on the surface of the earth forms a nearly constant quantity ; but being constantly in contact with, and acted on, by the caloric of the atmosphere, it merely changes its condition, being either in the form of vapour, in its ordinary fluid state, or congealed into solid masses of ice. This circulation, a sort of continual condensation and redistillation, furnishes the first condition of the origin of the water of springs. Aristotle explained the origin of the springs simply by the attraction of the mountains for aqueous vapour and clouds, which were condensed in their fissures into water. Vitruvius considered them to be owing to rain and snow, which penetrated through the fissures of the earth and formed subterranean reservoirs<sup>1</sup>. Descartes and Derham imagined a peculiar distillatory apparatus to exist in the interior of the earth, consisting of an assemblage of capillary tubes. There is no doubt that a more than sufficient quantity of aqueous fluid descends from the atmosphere than is requisite to keep up the constant flow of even the most copious springs. Yet, when we consider the great force of evaporation which returns into the air, a very large proportion of the fluid which it has just deposited upon the earth's surface before it sinks to any depth at all, and the enormous quantity of surface moisture carried off by the great fluviate channels which furrow the earth's surface into their grand receptacle the ocean ; we should hesitate admitting rain water to be the great storehouse of springs. Abundant vapours are exhaled from the surface of the ocean which are carried by the winds towards the land ; no sooner do they come in contact with the cold air, near the summits of mountains, than the water is precipitated and descends through the fissures in the rocky strata, and bursts out below in the form of springs. In tropical

<sup>1</sup> M. Vitruvii Pollionis de Architectura Libri decem, lib. viii.

regions, the quantity of aqueous vapour thus raised during the day from the ocean, and precipitated in the form of dew upon the hills, has been long ago noticed by Dr Halley<sup>1</sup> to amount to an enormous quantity. Probably by some such process as this are we to explain the formation of those ephemeral streams of water found in every district at the foot of its various eminences, especially when these are formed of columnar basalt, trap, or other rocks, traversed by numerous vertical fissures; and those which are forced to the surface by coming in contact with impenetrable beds of clay, &c., whose line of direction they are compelled to pursue. Those mineral waters which are observed to vary in their quantity, impregnation, and temperature, either periodically with the seasons, or after the lapse of a greater or less number of years, probably derive their origin directly from percolating atmospheric moisture.

With regard, however, to other classes of springs, which are certainly derived from a deeper source, the questions suggest themselves, even supposing the other two methods of disposal to be wanting. Could atmospheric water penetrate to such a depth? Would not insuperable barriers be opposed to its progress by the compact gneiss and mica-slate strata, and by the massive granite itself? And would it not be absorbed by the more porous clays and sandstones with which it would come in contact before reaching the fundamental crystalline rocks. These views are confirmed by the fact stated by Black, "that miners, the deeper they go, meet with less water<sup>2</sup>," although he considers this to prove the atmosphere to be the universal source of springs, yet only in a negative way, imagining it to shew that they cannot be derived from sea water. Perrault, De la Hire, and Dalton, have endeavoured to ascertain, by experiment, the depth to which rain and snow water can penetrate the rocky strata of the earth's crust, as well as the individual rocks which compose these strata. These, however, can give us very feeble ideas of the phenomena carried on by nature on the great scale.

<sup>1</sup> Philos. Trans. xvii. 468.—<sup>2</sup> Lectures, ii. 712.

It will be said that, although water cannot penetrate through the substance of the rocky masses, it may descend through rents and fissures. Openings, doubtless, exist in the enveloping strata of the globe, and extend, too, to a very great depth, as evinced by the inverse processes to those we are considering, viz. the phenomena of volcanoes and the very discharge of springs themselves. In the greater number, too, of the deepest mines, 1200 or 1600 feet beneath the earth's surface, the walls of the different galleries and levels are constantly bedewed with moisture, which probably finds its way downwards through these fissures. But certainly the water of boiling springs which emerge on the verge of perpetual snows at an altitude of 13,000 feet above the level of the sea, as in the Himalayahs, cannot be derived from the atmosphere, not to mention the peculiar relations of the Icelandic Geysers.

The theory which Scrope has so elegantly evolved regarding the causes of volcanic eruptions, and the physical nature of lavas when in a state of liquidity, and which has been brought as near to a demonstration as the subject admits; this theory may be brought to bear with signal advantage upon the formation of warm springs,—of many cold mineral waters,—and more especially upon the source from whence their water is derived<sup>1</sup>. It is well known that the great mass of the vapour which is discharged in such immense volumes from the crater of every volcano during an eruption, is aqueous vapour, or steam at a very high temperature, and consequently under strong compression. The muriatic, sulphurous, and carbonic acids,—the sulphuretted hydrogen and azote which give these vapours their characteristic qualities,—bear no comparison with the steam with which they are mixed or held in solution. This vapour is condensed

<sup>1</sup> *Scrope* (Considerations on Volcanoes, 1825, *passim*) views aqueous vapour to be the agent for maintaining the fluidity of lavas: or rather, if this view be correct, for holding in suspension the crystalline and comminuted particles of the solid rocks, which, on its escape, or condensation, in consequence of the sudden diminution of caloric and pressure on coming in contact with the atmospheric air, aggregate into solid streams.



into thick and heavy clouds above the volcano, and, unless dispersed by violent winds, undergoes a still further condensation into torrents of rain, which descend along the ravines of the mountain. When the volcanic chimney is of great elevation, and its orifice at a great distance from the focus of the eruption, the vapour is cooled sufficiently in its passage upwards to be condensed into water, which alone is discharged from the crater. Thus, in the Andes of South America, torrents of boiling water and mud are the sole products of the eruptions of their gigantic volcanoes. And is not the circumstance of water being the chief product of the Icelandic volcanoes, notwithstanding the comparatively insignificant height of their vents of emission, as strong a proof of the great depth of the focus, as the vast extent of space which here bears the marks of igneous devastation? After the cessation of an eruption, many fumaroles, or emanations of vapour, issue from the different lava currents, and from fissures in the sides or bottom of the volcano, which are at first wholly aqueous, but afterwards contain some mineral acids, and deposit different saline incrustations at the mouth of the fumarole, when the consolidation of the great lava mass in the interior of the crater impedes the escape of this vapour through that channel. With the source of this prodigious mass of aqueous vapour, we are unacquainted. Some considerations would lead us to refer it to the oceanic water. One thing, however, is certain, that it is discharged in great quantity from the bowels of the earth, and must therefore exist in enormous quantities in its interior. Now, this steam, instead of being discharged through volcanic vents, may, from the great depth of the igneous focus, or from the resistance of the superincumbent rocky masses being more than equal to its elasticity, be forced to pass through fissures existing in these masses, which, if of great length, will of course condense the vapour as it recedes from the source of its temperature and gaseous form, will in fact become true condensing tubes. In situations remote from volcanic craters, we have only to suppose these fissures of escape to be of greater length,

and to remain permanently open down to the liquid focus, in order to have a true theory of thermal and many analogous cold springs, wherever they may exist, at whatever altitude above the sea's level they may emerge to the surface. Does not this theory gain considerable strength from the violence with which they frequently spring forth?

In certain rare cases, when warm springs flow directly from the craters and cones of volcanic mountains, as in South America and the island of Java, they may be derived from water percolating through the still heated body of the mountain. An example of the process which Nature would follow in a case of this kind, is afforded by the volcano of Jorullo in Mexico. The rivers Cuitemba and San Pedro, which, before the heaving up of that great mass of lava, traversed the level country in an uninterrupted stream, now sink on one side into the great plain of the Malpays, and re-appear on the other in the form of perennial hot-springs. These were found by Humboldt, forty-six years after their formation, to possess a temperature of  $126^{\circ}$  F.; and we have been lately informed by Bullock, that they are now very little warmer than the mean of the atmosphere<sup>1</sup>, no doubt in consequence of the progressive cooling of the great mass of lava. A similar example, though of a more doubtful character, is cited by Scrope in the work above referred to. At Bertrichbad in Luxembourg, a thermal spring rises immediately below a spot where there are three extinct craters, of no very ancient date, which has probably percolated through the heated mass of subterranean lava, for its temperature is now below blood-heat, and in taste it does not differ from the purest spring water; so that at some former period its thermal and mineral qualities must have been much greater than at present, to acquire the reputation which it formerly enjoyed as a medicinal spring.

A powerful argument might also be drawn for deducing the water of a large proportion, and by far the

<sup>1</sup> *Scrope*, u. s. p. 129.

most important classes of mineral waters, from the focus of volcanic activity, from the nature of the gaseous and solid matters with which they are charged; but this I must reserve till we come to examine the origin of the ingredients of mineral springs.

The opinion entertained by some philosophers of the origin of the water of certain springs from the sea, has been pronounced by very respectable authority to be no less than absurd. "It is absurd," says an eminent chemist, "to suppose that they are fed by the sea; that the sea-water filtrates through the pores of the earth, and ascends through the interior of the high land and mountains, that the salt is separated from it during this filtration, and that the water breaks out at last to form springs. It is absurd to suppose that the water can ascend in this manner, contrary to its gravity, or that the salt is separated by filtration<sup>1</sup>." Is this not too strong language in arguing upon a subject like the present, where we have no means of directly verifying our conclusions? The impossibility of the salt being separated by filtration is but a weak objection, when it is considered that the union of the saline ingredients with the water is not more intimate than a state of simple solution. Besides, we have the positive experiment, that if, in a filtering apparatus, which has the form of an inverted syphon, we cause sea water to traverse a column fifteen feet high of dry sand, the water which first comes is fresh and potable; after a while it becomes saltish, and is finally salter than before, because the salt which remained behind in the sand is all washed through<sup>2</sup>. This sort of capillary action might perhaps be applied to explain the difference in the impregnation of many springs rising close to one another.

We have seen in the preceding chapter, that thermal springs are both more abundant, and in most cases possess the highest temperature, in the vicinity of active volcanoes; so that, in fact, an account of the distribution of a very large proportion of thermal waters is but an enu-

<sup>1</sup> *Black's Lectures*, ii. 712.—<sup>2</sup> *Kastner's Archiv*. xviii. 299.



meration of the geographic position of volcanoes on the earth's surface. If we pass in review the localities of these volcanoes, we see that they are all situate at no great distance from the sea, at least not in the centre of the great continents, and that by far the greater number, whether belonging to the systems of central or linear volcanoes, are islands rising out of the midst of the ocean<sup>1</sup>. We have indeed a notice by M. Remusat<sup>2</sup> of two volcanoes in the interior of central Tartary (about Long. 80° E., Lat. 45° N.), 400 leagues from the nearest sea, which is the Caspian. But this rests upon the authority of a Chinese document, and although it gains considerable credit from the oral communications received by M. Humboldt from the Tartars of the country, they have as yet not been described from the testimony of an eye-witness. At best it is only a solitary example, and would perhaps itself form a very doubtful exception to the general rule, as there are several extensive salt-water lakes scattered over these vast arid plains. It is hence more than probable that volcanoes stand in some relation to sea-water, and of course the warm springs also, which are so intimately connected with them.

The greater number of the thermal waters of these volcanic formations, situate at no great distance from the sea, are of the saline class,—the muriate of soda, and other salts found in sea-water, predominating in their composition. This is the case with those in the Island of Ischia,—those of Civita Vecchia,—in the Island of Milo,—and on the coast of Java.

I have selected the case of modern volcanic springs, because their phenomena are more open to our inspection, and more capable of being analyzed. Thermal waters, however, as well as the whole class of acidulous and alkaline cold mineral springs, exist in no inconsiderable numbers in situations remote from active volcanoes. But in chemical composition they are identical with, or pass into the former by insensible gradations; and we

<sup>1</sup> See the graphic sketch of the distribution of volcanoes by *Von Buch*, at the conclusion of his *Beschreibung der Canarischen Inseln*.—<sup>2</sup> *Annales des Mines*, v. 135.

have seen that they are associated with ancient igneous rocks,—with basalts, trachytes, porphyries and granites, whose subterranean relations, if their formation is really due to volcanic agency, cannot differ greatly from those which are daily subjected to our inspection. Our ignorance of the mode of that communication is certainly no argument against its possibility, or even its probability.

In our own times, instances have occurred, exemplifying the connection which evidently subsists, in some cases, between sea-water and volcanic operations. Humboldt records a great lava mass to have overcome the enormous pressure of the superincumbent Atlantic, and to have formed an island in the neighbourhood of Lancerote, one of the Canary group. The Isola Nuovo off Santorini, in the Grecian archipelago, was formed in the same manner, which to this day discharges copious boiling saline springs. And the volcanic island which existed for some months in the year 1831, off Sciacca in Sicily, was replaced, after its disappearance, by a column of boiling water rising to the height of from ten to thirty feet above the level of the sea,—a true submarine Geyser. Would not these destructive agitations, which almost invariably affect the sea, when the dry land is convulsed with earthquakes, indicate a connection between its waters and the focus of these oscillatory movements, somewhat more intimate than a mere mechanical concussion of its basin? Navigators, too, have frequently perceived strange motions in the midst of the ocean, which cannot be traced to any simultaneous phenomenon in the adjoining continents or islands<sup>1</sup>.

Perhaps an argument of some weight in favour of this origin of the water of many warm springs, might be deduced from the observations of Humboldt in South America, of a peculiar species of fish having been discharged along with torrents of hot water, from the colossal craters

<sup>1</sup> I have not here insisted on the proofs of the connection of the water of mineral springs with the focus of volcanic activity, which might be drawn from the influence of earthquakes upon them, because a copious citation of the chief facts bearing upon this, has been given at p. 210, and the inferences are too obvious to stand in need of farther illustration.

of the Andes<sup>1</sup>. This fish has been supposed an inhabitant of subterranean lakes, chiefly, as it would appear, from its nonconformity with any known species. But it is far more probable that it is a native of the deep recesses of the ocean, from whence it has been carried to the focus of volcanic agency. I am not aware that these torrents of hot water have been analyzed? If so, do the muriates or the sulphates predominate?

It is probable that the different saline and brine springs dispersed over the sandy plains of Holstein, Mecklenburg, Pomerania, and other analogous situations, at or near the shores of the North Sea and the Baltic, are derived from a simple filtration of sea-water. Artificial filtration shews, that the insoluble salts, as the sulphate of lime, are much changed, while the more soluble and less easily decomposable muriates remain unchanged, and are even increased in quantity in the water. Different earthy and rocky strata may possess different capillary attractions and affinities.

### SECTION III.

#### ORIGIN OF THE WARMTH OF MINERAL SPRINGS.

THIS inquiry will necessarily lead us in some measure into a consideration of the internal constitution of our planet; but I shall endeavour to limit these as much as is consistent with precision, together with an enlarged view of the subject. As the position of a great number of thermal waters does not permit of our positively deciding whether they owe their high temperature to the depth of their focus, or to the local peculiarities of the

<sup>1</sup> Observ. Zoolog. et d'Anat. Comparée, 1811, i. 21. The *Pimelodes Cyclopus*, belonging to the division *Silurus* of Lacepede. It is found in great abundance in the rivulets which descend from the flanks of the Andes, at the altitude of 10,800 feet, and is the only fish which exists in the waters of such an elevation. They are launched forth by Cotopaxi, Tungurahua and Sangay.



rocks which they traverse, in order to embrace all the possible sources of their heat, it will be necessary to bring forward a few of the facts which go to establish the existence of a general and inherent source of heat, independently of external influences, or of the local development of volcanic agency.

The elaborate and masterly researches of Fourier<sup>1</sup> have shewn, that the temperature of the earth's surface is as constant as the dimensions of its orbit, and the period of its annual revolution. \* He has shewn, that it derives its caloric from the three following sources:—1. The caloric diffused in the planetary spaces: 2. The caloric derived from the sun: 3. The caloric inherent to itself. The two first of these sources are capable of being estimated with rigid mathematical accuracy. But the last, with which we are more immediately concerned in investigating the sources of the caloric of springs, is, from the scantiness and the contradictory nature of many of the experiments, a problem which remains to reward the labours of some future analyst, when a sufficient number of accurate observations shall have been collected, to serve as the data for a sound basis of induction.

In its passage through the different canals and fissures existing in the interior of the earth, water may derive its heat:—

I. From volcanic action existing in a state of full activity.

II. From the remaining effects of a now extinguished volcanism upon the products of its operation or the mass of the surrounding strata.

III. From a general central cause of heat, increasing in a certain definite ratio as we descend from the surface into the interior of our planet.

Each of these causes will now be shortly considered, but in an inverse order to that in which they have just been announced.

What are the evidences of a progressive increase of

<sup>1</sup> *Essai sur la Temperature du Globe, et des Espaces planetaires*, 1827; and extract in *Annales de Chimie et de Phys.* xxvii. 136. 1824.

temperature as we penetrate deeper into the crust of the earth? This point may be determined in one or more of the following ways:—1. By the temperature of common perennial springs, which issue directly at the surface of the earth: 2. By the temperature of the springs in mines: 3. From the large bodies of water discharged by the draining levels of mines: 4. From the waters which remain stagnant in mines, in the form of great inundations or subterranean lakes: 5. By the direct temperature of the rock at different depths from the surface: 6. From the phenomena of artesian or overflowing wells.

It was long supposed that the mean atmospheric temperature of any spot was pretty exactly indicated by that of its perennial springs, or those bodies of water which issue forth in sufficient quantity and velocity not to be affected by the changes in the temperature of the air; and that these two elements decreased in a uniform ratio from the equator to the pole. Springs in mountainous districts seem not to give so certainly the temperature of the earth as those in the plains, because, in the former, we are never certain that they do not arise at a greater elevation, and issuing forth at a lower point, indicate a temperature inferior to what belongs to the ground. Neither can we select springs which issue from marshy ground. Those which, before emerging to the surface, are collected into a reservoir of greater or less size, show also a pretty constant temperature, but being always in contact with the air, they are liable to be affected by it. The same remark applies to wells, which have been sometimes employed to represent the temperature of the soil, if not more than twenty feet deep: they may in some cases be even colder, from the tendency of cold air to sink downwards, and the want of a free circulation. This parallelism of the temperature of perennial springs and the mean of the atmosphere, holds pretty exactly in middle latitudes, especially on the Atlantic shores of Europe, as proved by the long-continued experiments of Playfair<sup>1</sup>. But Wahlenberg, from a se-

<sup>1</sup> He found the temperature of a spring of the above description

ries of thermometrical observations in Sweden<sup>1</sup>, was the first to point out the singular fact, that, in high latitudes, when the atmospheric temperature fell below a certain point, that of springs was observed to decrease at a much slower rate, till it finally exceeded the former. The effects of this excess were manifestly seen on the vegetation of these districts, which flourished and came to maturity when exposed to an atmospheric temperature lower than that at which estivation is known to take place. Those trees and shrubs whose roots penetrated deep into the soil, follow in these northern regions the periods of the terrestrial, not of the atmospheric temperature. This difference was even so great, that rye, which requires for its growth a temperature of not less than  $46^{\circ}.4$  F., was produced in situations where it did not exceed  $35^{\circ}.6$ . These observations on the phases of the arctic vegetation, have been recently confirmed by others made in the northern part of the Uralian range. So that it seems to be a general law, that in all northern countries, the mean temperature of the earth is higher than that of the air, and the difference appears to increase as we advance north, or as the cold of winter becomes more severe, as will appear by the subjoined table.

None can fail being struck with the beauty of this arrangement in the economy of Nature; for by this means polar regions are enabled to nourish many plants of indispensable utility to man. Were it not for this these vast regions would be entirely destitute of life; for who could suppose colonization and culture to take place on a soil whose temperature was  $4^{\circ}$  or  $5^{\circ}$  under the freezing point? Yet the atmospheric temperature is no higher in situations where there are flourishing towns, and harvests are gathered with regularity and profit. Such is the case with a great part of Siberia, the upper part of Finland, and many inhabited valleys of Sweden.

near Edinburgh,  $47^{\circ}.7$  F.; and from a series of observations, continued for six years, he concluded its mean atmospheric temperature to be  $47^{\circ}.8$ .—*Annals of Philos.* Feb. 1818.

<sup>1</sup> Observations on Heat of Springs and Vegetation in Sweden, translated in Thomson's *Annals of Philosophy*, iv. 22. 1814.



Wahlenberg sought an explanation of this phenomenon in the investing covering of snow, which excluded the winter's cold on account of its bad conducting power;—an opinion which has been adopted by many others. But the cover of snow could hardly suffice, by its duration for so many months, to prevent the radiation of heat from the soil. It rests besides on the erroneous supposition that the atmospheric warmth penetrates into the ground by communication to its mass. But the observations of Saussure, who found that six months were required for its penetration to the depth of thirty feet, are sufficient to shew the length of time before such a distribution could be established; as also the experiments which have been since carried on in a well at Geneva for the space of ten years, the temperature of which was constantly at its minimum when it was greatest at the surface, and at its maximum at the period of greatest cold. Besides, why should northern regions be more protected from such a radiation than more southern ones, since it seems to be well established that less snow falls in high latitudes?

The universality, however, and true nature of this discordance was put beyond a doubt when, taking the other extreme, the observations of Humboldt in South America<sup>1</sup>, of Von Buch in the Canary Islands<sup>2</sup>, Dr John Hunter in Jamaica<sup>3</sup>, Smith in Congo and the Cape Verd Isles, and Hamilton in Nepaul, shewed that in low latitudes, at the equator, for example, the mean atmospheric temperature was *higher* than that of the perennial springs. Two progressions were thus established to exist, which follow different rates of decrease from the equator to the pole; the first, that of the air, which is the more rapid; and the second, that of springs, or of the earth, which is slower. In order that this fact may be presented to the eye in a clear form, the following table contains the most striking of these observations, reduced to the level of the sea on a height not exceeding 1500 feet.

<sup>1</sup> Gilbert's Annalen, xxiv. 46.—<sup>2</sup> Poggendorff's Annalen, xii. 403.  
—<sup>3</sup> Phil. Trans. for 1788, p. 59.

PLACE.	LAT.	Alt. in Feet.	Terres- trial Temp.	Atmo- spheric Temp.	OBSERVERS.
Congo .....	9 S.	1480	° F. 72.9	° F. 78.1	Smith
Cumana .....	10 $\frac{1}{4}$ N.	0	78.1	82.4	Humboldt
St Jago, Cape Verd } Isles .....	15	0	76.1	77.0	Hamilton
Rockfort, Jamaica ...	18	0	79.0	80.6	Hunter
Havannah .....	23	0	74.3	78.1	Ferrer
Nepaul .....	28	0?	73.8	77.0	Hamilton
Teneriffe .....	28 $\frac{1}{2}$	0	64.4	70.9	Buch
Cairo .....	30	0	72.5	72.5	Nouet
Cincinnati .....	39	525	54.3	53.8	Mansfield
Philadelphia .....	40	0	54.9	54.3	Warden
Carmeaux .....	43	984?	55.4	57.9	Cordier
Geneva .....	46	1148	52.0	49.3	Saussure
Paris .....	49	246	52.7	51.6	Bouvard
Berlin .....	52 $\frac{1}{2}$	131	50.2	46.4	
Dublin .....	53	0	49.3	49.1	Kirwan
Kendal .....	54	0	47.7	46.2	Dalton
Keswick .....	54 $\frac{1}{2}$	0	48.6	48.0	
Kisnekejewa, East } Russia, .....	54 $\frac{1}{2}$	984	39.9	34.7	Kupffer
Edinburgh .....	56	0	47.7	47.8	Playfair
Kasan .....	56	98	43.2	37.4	Kupffer
Carlsrona .....	56 $\frac{1}{4}$	0	47.3	47.3	Wahlenberg
Nishneytagilsk, } East Russia .....	58	656	37.2	31.5	Kupffer
Werchoturie, do. ....	59	656	36.3	30.4	Do.
Bogoslowsk, do. ....	60	656	35.4	29.3	Do.
Upsal .....	60	0	43.7	43.1	Wahlenberg
Umeo .....	64	0	37.2	33.3	Do.
Giwartenfäll, Sweden,	66	1640	34.2	25.2	Do.

But, besides the fact of the nonparallelism of the terrestrial and atmospheric temperatures, a mere inspection of the above table shews that the temperature of the earth is different under the same latitude but under different meridians; that, in fact, as Kupffer has expressed it<sup>1</sup>, a law similar in its principles, though of course depending upon very different causes, to the beautiful theory of isothermal lines, exists with regard to the temperature of the globe. That these *isogeothermal* lines, as they may be called, are neither parallel to the equator

<sup>1</sup> Edin. New Phil. Journ. viii. 237; 1830.

nor to the isothermal, but describe ordinates and abscissæ peculiar to themselves.

The observations which we hitherto possess may, under this point of view, be comprised under four principal meridians or meridional zones; that of the Urals, of Upsal, of Paris, and Cumana. Arranged in this manner, they would assume the following form<sup>1</sup>:

*1st Meridian of Longitude 60° E.*

Kisnekejewa	Lat. 54° $\frac{1}{2}$ N.	Terrestrial Temp.	42°.6 F.
Nishneytagilsk	... 58	.....	38 .9
Werchoturie	... 59	.....	38 .0
Bogoslowsk	... 60	.....	37 .2

*2d Meridian of Longitude 20° E.*

Congo	Lat. 9° S.	Terrestrial Temp.	77°.0 F.
Cairo	... 30 N.	.....	72 .5
Carlsrona	... 56 $\frac{1}{4}$	.....	47 .3
Upsal	... 60	.....	43 .7
Umeo	... 64	.....	37 .2
Giwartenfiäl	... 66	.....	38 .7

*3d Meridian of Longitude 0°*

St Jago	Lat. 15° N.	Terrestrial Temp.	76°.1 F.
Teneriffe	... 28 $\frac{1}{2}$	.....	64 .4
Carneaux	... 43	.....	58 .1
Geneva	... 46	.....	55 .2
Paris	... 49	.....	53 .4
Dublin	... 53	.....	49 .3
Keswick	... 54 $\frac{1}{2}$	.....	48 .7
Edinburgh	... 56	.....	47 .7

*4th Meridian of Longitude 80° W.*

Cumana	Lat. 10° N.	Terrestrial Temp.	78°.1 F.
Rockfort	... 18	.....	79 .0
Havannah	... 23	.....	74 .3
Cincinnati	... 39	.....	55 .6
Philadelphia	... 40	.....	54 .9

Mayer conceived that the mean temperature of the air,

<sup>1</sup> As some of the stations are at a considerable altitude above the sea, it is necessary to reduce them to its level. In the want of observations to determine exactly the decrease in the temperature of the earth with the altitude, we may assume that the decrease in the temperature of springs is subject to nearly the same law as that of the air, and that, if any difference exists, the first decreases more slowly. We may, therefore, assume a decrease of 1° F. for 364 feet of ascent.



under a given parallel, might be expressed by the formula :

$$27^{\circ} \cdot \cos^2 \text{latitude} = \text{M. T. centigrade.}$$

Professor Kupffer conceives that the distribution of the terrestrial temperature under the same meridian may be expressed pretty well by the following formula :

$$a - b \sin^2 \text{lat.} = \text{terrest. temp.}$$

where  $a$  and  $b$  are constant. Combining under the third meridian the observations of Paris and Edinburgh, to find out the constant numbers, we obtain,

$$a - b \sin^2 56^{\circ} = 47^{\circ}.7,$$

$$a - b \sin^2 49^{\circ} = 53^{\circ}.4,$$

from which,

$$a = 97^{\circ}.4 \text{ and } b = 47.0.$$

For the second meridian, using the observations of Cairo and Upsal,

$$a = 86.9 \text{ and } b = 57.6.$$

For the first meridian, from the observations of Kisnekejewa and Bogoslowsk,

$$a = 83^{\circ}.5 \text{ and } b = 61^{\circ}.9.$$

And for the fourth meridian, from the observations of Rockfort and Cincinnati,

$$a = 86^{\circ}.0 \text{ and } b = 75^{\circ}.8.$$

Could the formula be depended on, it would be easy to find the terrestrial temperature for every degree of latitude under the different meridians, for which we possess two observations; and in this manner we might trace the curves of the isogeothermal lines. But, however interesting these comparisons, it must be confessed that this branch of physical science is but in its infancy, that our observations are few in number, confined to a limited portion of the earth's surface, and particularly defective in the equatorial regions. The cautious philosopher must therefore hesitate in forming a theory too prematurely upon such confessedly scanty data.

It would be foreign to the purpose of the present treatise to enter into a detail of the relations which the terrestrial temperature might be imagined to bear to

other cosmical phenomena, such as the boundary of the polar ices and the distribution of the earth's magnetism. It is sufficient for our present purpose to have pointed out the existence of such laws regarding the distribution of the earth's temperature, deduced from the phenomena of springs, as seem to indicate an inherent calorific power separate and distinct from the solar influence or the temperature of the atmosphere.

A fact strongly illustrative of the preceding principles is recorded by Von Buch in his memoir on the temperature of springs. Can it be considered as confirmatory of the idea that extensive plains are destitute of warm springs, to which I have adverted in the preceding chapter? At Jakutsk, in Siberia, Gmelin found the soil frozen to a depth of 100 feet in the middle of summer; while again, at Hudson's Bay, the mean temperature of which is much under the freezing point, springs issue forth from under a cover of snow and ice throughout the whole winter. This distinguished geognost rejects the observation of Gmelin as doubtful, resting merely on the testimony of Cossacks who were employed to dig the wells, because it is at variance with the law, supposed by him to be universal, of the terrestrial being higher than the atmospheric temperature in high latitudes. But when we combine this observation with that made at Hudson's Bay, should it not rather be considered as an additional proof of the irregularity in the distribution of the terrestrial temperature?

When, however, we endeavour to establish the terrestrial temperature at the surface of the earth as a general law of nature, and not deducible from the mean temperature of the air, I must apprise the reader that this series of points of invariable temperature are not found at the surface of the soil, but at a certain depth beneath it. This invariable stratum forms the limit to which the changes of the temperature of the air with the seasons extend. Fourier has come to the analytical conclusion, that this point is found at the depth of sixty or eighty feet below the surface of the soil. Although this stratum possesses an invariable temperature, it cannot, we

have seen, be considered to represent the mean temperature of the point of the surface to which it corresponds vertically<sup>1</sup>. They agree, it is true, pretty nearly in middle latitudes, but the divergence progressively increases both to the pole and the equator. The invariable stratum probably does not possess a uniform curvature, but is modified into various sinuosities dependent on the nature of the soil, the presence of mountains, valleys, lakes, seas, and many other causes, which can only be appreciated by experiment. Unfortunately we are as yet not in the possession of a single experiment capable of fixing, for any point, the precise limit of this invariable stratum. The beautiful series of experiments which have been carried on for more than fifty years in the caves of the Observatory of Paris, shew that, at the depth of ninety-two feet beneath the surface, the temperature is invariable; but as it is 2°.2 F. below the mean temperature at the surface, it is probably below the stratum of invariable temperature. Much may be expected from the series of experiments which have been commenced by M. Arago with alcohol thermometers, placed at different points below the surface, to the depth of twenty-six feet.

All variable springs are coldest at the end of spring, and hottest in autumn: those which are subject to the greatest variations reach their highest temperature in the northern hemisphere about the end of August, a short time after the temperature of the air has arrived at its maximum; those which are more constant reach their highest temperature in September.

It is, however, by observations made in mines, or other subterranean cavities, that we can alone infer the reality of a *progressive* increase of temperature the deeper we penetrate into the crust of the earth, or determine the rate of this increase. The thermometrical indica-

<sup>1</sup> I am surprised to see that, in an estimable work recently published (*Pouillet*, *Elemens de Physique et de Meteorologie*, ii. 641, 1830), the stratum of invariable temperature is said to be, "a peu-pres la temperature moyenne du point de la surface," as a general principle.



tions obtained in this way are, however, liable to many fallacies from the difficulty of excluding the disturbing influence of external causes.

The warmth experienced on descending into mines very early attracted the attention of observers; but it was attributed, without farther inquiry, by one party to the decomposition of pyrites, and by another to a central fire, two hypotheses by which the older philosophers were very fond of explaining facts with which they were in any way embarrassed. Since the revival of a rigid experimental philosophy, the question of subterranean temperature has assumed a rank among one of the greatest problems in the physics of the earth. Gensanne seems to have been the first observer who carried a thermometer to different depths, and ascertained the important fact that *the temperature increases with the depth*<sup>1</sup>. His experiments commenced in the year 1740, and were carried on in the lead mines of Giromagny near Befort. As they possess a historical interest, I may here briefly state his conclusions :

Depths.		Temperatures.
331 feet English,	.	55° F.
670 ditto,	.	56
1010 ditto,	.	66
1420 ditto,	.	73

Saussure, in 1785, made similar experiments to the depth of about 700 feet, in the deserted galleries of an excavation which had been made at the salt-works of Bex, to which I have formerly alluded (p. 274)<sup>2</sup>. Humboldt and Freiesleben made numerous experiments in 1791, in the Freyberg Mines<sup>3</sup>; and the former observer, during his memorable travels in the New Continent, experimented on the temperature of mines to the great depth of 1713 feet. In 1802, Daubuisson gave new life to the question by his observations in Saxony<sup>4</sup>, and in the lead and silver mines of Brittany in 1806<sup>5</sup>. In 1805, 1806, 1807, and 1815, we have the interesting series in the mines of Saxony by M. Trebra<sup>6</sup>. In our own country

<sup>1</sup> *Mairan*, Dissertation sur la Glace, 1749, p. 60.—<sup>2</sup> *Voyages dans les Alpes*, § 1088.—<sup>3</sup> *Annales de Chim. et de Phys.* xiii. 210.—<sup>4</sup> *Description des Mines de Freyberg*, tit. iii. 151. 186. 200.—<sup>5</sup> *Journal des Mines*, xxi. 119.—<sup>6</sup> *Annales des Mines*, tit. i. 377; and iii. 59.

are the observations of Messrs Bald, Dunn, and Fenwick, in the coal-mines of the north of England, and the long continued and excellent observations of Mr Fox in the Cornish mines. We are, however, chiefly indebted to the classical and critical essay of M. Cordier<sup>1</sup>, in which are collected and discussed, in a very able manner, the merits of all the preceding observations as well as the precautions necessary to obtain accurate results, in addition to several experiments of his own. And, lastly, I may notice the beautiful series of experiments at present carrying on in the Kurprinz mine under the superintendence of Professor Reich of Freyberg, and which are not yet published; but for accuracy and completeness, if I mistake not, surpass all that have yet been published on subterranean temperature.

I need hardly observe the necessity in such experiments, where minuteness and accuracy are the only qualities which can render them susceptible of comparison with each other, that the thermometers employed should be corrected either before or after any series of observations by the actual verification of their freezing and boiling points, or by comparing them with the normal thermometer of an observatory where a regular series of observations are carried on. And it cannot be sufficiently regretted that, in the great majority of the experiments, these verifications have been either entirely neglected, or the observers have failed to detail them, which can alone give confidence in instituting comparisons between different countries.

More than two-thirds of the observations must be entirely rejected, as having been made upon the air in subterranean cavities, too fluctuating a medium to afford any thing like accurate results, unless in cavities of small extent and entirely excluded from all foreign influences, such as the presence of workmen, the access of water, or the contact of the external air, in fact, hermetically closed up so as to acquire entirely the temperature of the rocky walls. These disturbing causes render the air

<sup>1</sup> Mem. du Museum d'Hist. Naturelle for 1827; and Edin. New Phil. Journal, v. 277, and vi. 32, 1828-29.

of mines quite unfit for giving accurate numerical results of the rate of increase in the terrestrial temperature. The access of external air is the most general of these agents; its effect of course varies with the degree of ventilation and its temperature at the surface, as well as the direction of the different galleries and shafts, but, generally speaking, it has the effect of diminishing the real heat of the bowels of the earth. Cordier ascertained that the influence of the causes which vary incessantly the temperature of the air in mines, extended even to the bottom of the most distant works. The action of infiltrated water is more uniform in its operation, but it tends also to diminish the true temperature. The other disturbing cause, viz. the heat disengaged from workmen and their lights, acts in an opposite direction to the two former, tending to raise the temperature of the air above that of the surrounding rock. Its effect varies with the number and distribution of the lights and workmen, the capacity and depth of the workings, and the manner in which it combines with the other disturbing causes. M. Cordier has endeavoured to obtain numerical expressions for the amount of this disturbing cause. These results can, however, only be considered as a vague approximation. He conceives that each miner disengages hourly a quantity of heat capable of raising  $1^{\circ}$  F. 34,456 cubic feet of air taken at  $54^{\circ}$  F. of original temperature; and that four ordinary lamps produce about as much heat as four workmen. A striking example of the magnitude of this cause was furnished by the Ravin mine at Carmeaux, the air of the most unfrequented galleries in the lower stage of which was  $11^{\circ}$  above the true temperature of the surrounding zone of rock.

The experiments which have been carried on for so many years below the Observatory of Paris, in the ancient quarries, are exempt from all the above mentioned disturbing causes, and merit the greater confidence from the uniformity of their indications for such a length of time, and in all seasons and circumstances of the external air. Since 1783, when the thermometer was first established by Cassini and Lavoisier, it has not varied



0°.25 Cent.; and it was ascertained that these oscillations were caused by an accidental current in the subterranean quarries. In the course of a year its variations never exceed 0°.03 Cent.<sup>1</sup>. Its indications are :

*Observation on Subterranean Air.*

PLACE.	Depth in Eng. feet.	Tempera- ture.	M. T. of country.	Depth in feet for increase of 1° F.
Observatory of Paris, CASSINI & BOU- VARD, 1783-1830, }	92	53°.3 F.	51°.1	41.8

The greater number of the remaining third of the experiments have been made on the water which occurs in different forms in mines, which, although not affected so much as the air by external influences, and exhibiting a greater uniformity in their indications, are still open to many sources of fallacy. Viewed merely as a mass of approximative documents, we can, without hesitation, conclude that there is a remarkable increase in the subterranean heat. The experiments have been made at different seasons, and all indicate a temperature higher than the mean of the country. Whatever influence the former disturbing causes may have, there are many observations whose testimony cannot be refused, though, as we shall see, the numbers are not sufficiently accurate to deduce the law of the increase of temperature with the depth.

Whatever source the water of the *springs* of mines are derived from, we cannot depend upon their indicating

<sup>1</sup> The following is a description of the apparatus:—On the floor of the caves, at ninety-six feet below the pavement of the Observatory, is a mass of stone four feet high, on the top of which is a large glass vessel eighteen inches high and twelve or fifteen in diameter, filled with fine sand, in which is the thermometer with its bulb near the bottom of the vessel. The scale of the thermometer is of glass enclosed in a frame of copper, which is fixed to the edges of the glass vessel by means of traverses. The thermometer is of mercury, carefully constructed by Lavoisier: its bulb is two inches and a half in diameter; the tube is very fine, a degree centigrade occupying about forty-two or forty-three lines. Thus, 0°.005 cent. are easily distinguishable. Its graduation only extending 15° or 16° above the freezing point, there is a small cavity at the top to receive the excess of mercury if the temperature should rise above 16° cent.

the true temperature of the rock from which they issue. When derived from infiltrating moisture, they may vary with the season, being sometimes higher sometimes lower than the mean temperature of the country. Even when uniform at all seasons, and for several years, as in the acidulo-chalybeate spring in the Kurprinz mine at Freyberg, we cannot be sure that they do not belong to the class of thermal waters, to which the workings of the mines have given a subterranean exit. As, however, all the observations on springs of mines agree in indicating a temperature higher than the mean of the country, they merit attention as approximative results.

*Observations on Subterranean Springs.*

COUNTRY, OBSERVER, and DATE.	MINES.	Depth in feet.	Temperature		Depth in feet for increase of 1° F.
			Of Springs.	Of Country.	
<i>Saxony.</i> Daubuisson, End of Wint. 1802,	Lead and silver mine of Jung- hohe-Birke, }	256	48.9	46.4	102.4
	Do. of Beschert- gluck, ..... }	712	54.5	46.4	87.9
	Do. do. }	840	56.8	46.4	80.7
	Do. of Himmel- fahrt, ..... }	735	57.9	46.4	63.9
M. G. Oct. 1830,	Do. of Kurprinz,	634	80.1	46.4	18.8
<i>Brittany.</i> Daubuisson, Sept. 1806,	Do. of Poulla- ouen, ..... }	128	53.4	52.7	182.0
	Do. do. }	246	53.4	52.7	351.0
	Do. do. }	459	58.3	52.7	82.0
	Do. of Huelgöet,	197	54.0	51.8	89.5
	Do. do. }	262	59.0	51.8	36.4
	Do. do. }	394	59.0	51.8	54.7
	Do. do. }	755	67.5	51.8	48.1
<i>Cornwall.</i> Mr Fox, Pub. 1821,	Copper mine of Dolcoath, ... }	1440	82.0	50.0	45.0
<i>Mexico.</i> Humboldt,	Silver mine of Guanaxuato, }	1713	98.2	60.8	45.8

The rates of increase, as deduced from springs, thus vary from 19 to 351 feet for  $1^{\circ}$  F. But it is curious to remark how nearly the results obtained by Fox and Humboldt, at the greatest depths at which experiments have yet been made in mines, correspond with those obtained at the Paris Observatory. The mean of all the observations gives a rate of 92 feet for each degree of temperature.

The experiments of Mr Fox on the water discharged from the *draining levels* of the great mines of Cornwall are very important, in establishing the fact of the subterranean temperature being higher than that of the atmosphere. The waters which issue from most of the tin and copper mines of Cornwall are conducted by various branches into a great adit, which carries them over the valley of the Carnon, and which, at its termination, pours forth 1400 cubic feet of water in a minute, or about 60,000 tons daily. In one of the branches leading to the great adit, discharging the water of six mines, from 900 to 960 feet deep, the temperature of the water, at half a mile from its mouth, was  $73^{\circ}.4$  F. A second branch, leading off the water of ten mines, from 660 to 720 feet deep, was  $66^{\circ}.6$  a third of a mile from its mouth. A third branch, draining seven mines, from 600 to 660 feet deep, was  $64^{\circ}.9$ . And the united streams at the mouth of the great adit, had a temperature of  $69^{\circ}.3$ , which is  $19^{\circ}$  more than the mean temperature of the country. Unfortunately the author has omitted many details of importance; but if we assume with M. Cordier, that the working of these mines occupies 2000 miners and 2000 lamps, burning half an ounce of oil per hour, it will be found, from the data formerly mentioned, that the heat produced would hardly raise the temperature of a mass of water equal to that which flowed off in the same time by half a degree Fahrenheit.

The last class of observations on subterranean waters which merit attention, from the uniformity of their results, are those on the temperature of *great inundations*, which remain stagnant in mines. Generally speaking, their temperature will be somewhat lower than that of the rock, especially when their depth is not very consi-



derable. They lead, however, to uncertain results, both from the contact of the external air, and the mixture of strata of water of different temperatures. The following is a synoptic Table of the most important observations :

*Observations on Subterranean Inundations.*

COUNTRY, OBSERVER, AND DATE.	MINES.	Depth in Feet.	Temperature		Depth in feet for In- crease of 1° F.
			of Water.	Mean of Country.	
<i>Cornwall.</i> Mr Fox, Published 1822 <sup>1</sup> ,	Copper-mine of N. Huel Virgin, inundation very deep, } Ditto of Nargiles,—inundation very deep,..... } Ditto of Gwennap,—inundation 420 feet deep,..... } Ditto of Tintang,—inundation 59 feet deep,..... } Ditto of Huel Maid,—inundation 180 feet deep,..... } Copper and tin mine of Tincroft,—inundation 59 ft. deep, } Tin mine of United Mines. — inundation 180 feet deep, }	234 528 600 643 757 757 1081	60.1 57.9 60.1 63.5 60.1 63.0 80.1	50° 50 50 50 50 50 50	23.2 66.8 59.4 47.6 74.9 58.2 35.9
<i>Saxony,</i> Daubuisson, End of winter 1802,	{ Lead & silver mines of Junghohe-Birke, — inundation 118 feet deep, }	1044	63.0	46.4	62.7
<i>Brittany,</i> Daubuisson, Sept. 1806,	{ Ditto of Huelgoet, inundation 52 feet deep,..... }	781	65.8	51.8	55.8

<sup>1</sup> The following statement appears of some of the Cornish mines in 1831 :

Tintang, copper, parish of Gwennap, . . . 1068 feet, 82° F.

Huel Vor, tin, near Helston, . . . . . 1254 79

Poldice, copper and tin, parish of Gwennap, 1056 99

Only three persons are employed near each station. 1,800,000 gallons of water are pumped out from the last mines in twenty-four hours. All the mines are in clay-slate.

The rates of increase here vary from 23 to 75 feet for 1° F. The mean of all the observations gives a rate of 54 feet for each degree.

The last class of experiments, are those which have been instituted with the view of ascertaining directly the temperature of the *rock* at different depths from the surface. Their number is very inconsiderable, and must unfortunately be still more limited, from the want of all the accessory precautions having been employed in the greater number, which are indispensable to insure accurate results.

The first set of experiments are those which were made many years ago in two mines of Saxony by Von Trebra. Stationary thermometers were placed at different levels, remote from works in activity, and where there was little circulation of air. Each thermometer was enclosed in a niche, glazed on the fore part, and contained in a glass tube: the ball was lodged in a cavity wrought directly in the rock. The observations were continued for a long time, and in one of the mines were repeated three times a day for two years. They were made by the working master miners, and verified from time to time by superior officers. These arrangements, however, are by no means unexceptionable. In mines so old, so much frequented, and so perfectly aired, the temperature of the walls has had time to experience many modifications, especially when we consider the great extent of the works, the magnitude of the excavations, and the abundance of water.

The second set of experiments are those made by simply sinking the thermometer a few inches in the earthy matter and rubbish of the floor of the galleries. In this way, the temperature is very far from accurate: it represents a rate compounded of that of the rock, the air, and the infiltrating moisture.

The third series of observations on the temperature of the rock, are those alone on which we can confidently rely, when made with the necessary precautions. The first of these is one made by Mr Fox in the mine of Dolcoath, where a thermometer was kept for eighteen

months sunk to the depth of 3 feet 3 inches in the rock of the gallery. I have not seen any description of the apparatus employed, although, from the known talents of the observer, and his experience in every thing that relates to subterranean temperature, there can be no doubt that it would be instituted with all the accuracy which such an important experiment demanded. The second of these are carrying on at four different stations in the Kurprinz mine at Freyberg, with thermometers of a peculiar construction, under the superintendence of Professor Reich of Freyberg. As the attention to insure accurate results is what constitutes the great value of these experiments, I shall make no apology for detailing, with a little minuteness, the manner in which they are made.

The bulb of the thermometers, and more than three feet of the tube, are enclosed in a brass cylinder, closed at bottom, and about three-fourths of an inch in diameter. The upper part of the tube only, about twelve or fifteen inches in length, which remains out of the cylinder, is graduated. One-tenth of a degree of Reaumur is clearly distinguishable, and smaller quantities can be correctly estimated. The space between the non-graduated part of the tube and the brass case is filled with fine sand. With these precautions, the cylinder is sunk its whole length into a narrow bore obliquely driven into the solid gneiss walls of the galleries, leaving only the graduated scale on which the temperature may be observed, and the interval between the cylinder and the walls of the bore are in the same manner filled up with sand. The bulb is thus sunk three feet into the solid rock, and excluded from the air by the sand interposed between the cylinder and the rock, and between the tube of the thermometer and the cylinder. The bores are situated in little chambers hewn out of the rock, and closed by a door, the key of which is only in the hands of the master of the mine. So delicate are these thermometers, that they indicate slight variations from passing currents, or even the too long proximity of the observer. The four thermometers, which are placed in the Treib-



shacht, the third, fifth, and eighth galleries, are observed three times a-week, Mondays, Wednesdays, and Fridays, by Steiger Richter, the captain of the mine. The time of observation is either 7 A. M. or 12 noon. The galleries in which they are placed are far remote from the present workings, not at all frequented, without a free circulation of air, and remarkable for their dryness.

*Observations on the Rock of Mines.*

COUNTRY, OBSERVER, AND DATE.	MINES.	Depth in Feet.	Temperature		Depth for In- crease of 1° F.
			of Rock.	Mean of Country.	
<i>Saxony,</i> Von Trebra, { 1805-6-7,	<i>1st Kind of Observations.</i>				
	Lead and silver mine of Beschert Glück, }	591	52.2	46.4	101.0
Von Trebra, { 1815,	Ditto of Alte Hoff- nung Gottes, }	853	59.0	46.4	67.7
	Ditto, ditto, . }	236	47.7	46.4	174.7
	Ditto, ditto, . }	552	55.0	46.4	63.7
	Ditto, ditto, . }	880	59.0	46.4	69.8
	Ditto, ditto, . }	1246	65.7	46.4	64.4
<i>Cornwall.</i> Mr Fox, pub- { lished 1821, {	<i>2d Kind of Observations.</i>				
	Copper United Mines, }	1142	87.4	50	30.5
<i>Carmaux,</i> Cordier, { 1827, {	Ditto, ditto, . }	1201	88.0	50	31.1
<i>Littry,</i> Ditto, ditto, {	Coal-mine of Ravin, }	597	62.8	52	55.3
	Ditto of Castillan, }	630	67.1	52	40.8
<i>Decise,</i> Ditto, ditto, {	Coal-mine of St Charles, . }	325	61.0	52	36.1
Ditto, ditto, {	Coal-mine of Jacobé,	351	64.0	52	29.2
	Ditto, ditto, . }	561	71.7	52	28.5
<i>Cornwall,</i> Mr Fox, pub- { lished 1820, {	<i>3d Kind of Observations.</i>				
	Copper-mine of Dol- coath, . . }	1381	75.6	50	54.0
<i>Saxony,</i> Reich, Oct. { 1829-Oct. { 1830; 12 { mos. obs. <sup>1</sup> {	Lead and silver mine of Kurprinz, }	18	51.8	46.4	
	Ditto, ditto, . }	413	59.6	46.4	31.3
	Ditto, ditto, . }	686	62.5	46.4	42.6
	Ditto, ditto, . }	1063	67.7	46.4	49.9

<sup>1</sup> The depth of these four stations is perpendicular from the surface: the medium inclination of the shaft is 72°.

The oscillations of these last thermometers during the twelve months were,

Station 1st,	Maximum, 59.7	Minimum, 43.9	Range, 15.8
~~~~~ 2d,	~~~~~ 61.2	~~~~~ 57.9	~~~~~ 3.3
~~~~~ 3d,	~~~~~ 62.6	~~~~~ 62.4	~~~~~ 0.2
~~~~~ 4th,	~~~~~ 68.4	~~~~~ 67.4	~~~~~ 1.0

The rates of increase, deduced from the first and second kind of observations, thus vary from 29 to 175 feet for 1° F. The mean of all the observations gives a rate of 61 feet for each degree of temperature.

Deduced from the third kind of observations, it varies from 31 to 54 feet. The mean gives 44 feet for each degree.

I have rejected the rate inferred from the observations at the first station in the Kurprinz mine, as the extent of the annual variation evidently indicates that, at this small depth, the temperature is entirely modified by external influences.

In all the observations on subterranean temperature, it will be seen the rate of increase has been calculated by comparing the experiments at the different depths with the mean temperature of the country. Of course, the accuracy of the comparison depends upon this mean temperature being precisely known. This is only the case with the Paris observatory. At all the other places, the error may amount to perhaps a degree in excess or defect.

We cannot fail being struck with the close approximation of the results in situations remote from each other, where the observations are of such a nature as to be almost or quite unexceptionable. Thus,

The Caves of the Paris Observatory give a rate of	41.8 feet.
The rock of the Dolcoath mine, . . . . .	54.0
The rock of the Kurprinz mine, station 2d, . . . . .	31.3
~~~~~ station 3d, . . . . .	42.6
~~~~~ station 4th, . . . . .	49.9

From which we obtain a grand mean of 43.9 feet for each degree of temperature.

Or, if we add to them the observations on springs at Dolcoath and Guanaxuato, the coincidence of which with

one another and with the others, can hardly be considered accidental, although the kind of observations is somewhat exceptionable, the mean becomes 44.3<sup>1</sup>.

The last class of observations from which we infer the reality in the increase of subterranean temperature, are the phenomena of *Artesian* or *Overflowing Wells*, or those narrow artificial orifices which give exit to subterranean reservoirs of water. The temperature of the water as it appears at the surface, seems to be almost exactly that of the source from which it derives its origin; for it is invariable, and increases as the depth of the bore becomes more considerable. M. Arago has imagined in this way to find the temperature of the earth at different depths, by observing that we can in some measure judge of the depth of a well by the temperature of the water. The converse of the proposition, however, is somewhat more doubtful, viz. that from the temperature of the water, we can infer that of the earth at the given depth. For the water of these wells must be subject to many of the disturbing causes we have seen to operate on the water of mines, though perhaps in a less degree. Atmospheric air does not obtain access to these subterranean reservoirs, but they are exposed to the full action of infiltrating moisture, which tends to mingle together the temperature of different rocky strata. Besides, they may, and probably are, the recipients of subterranean springs, which not unfrequently may belong to the thermal class, and in every case bear the temperature of a different level. Upon these grounds, I think that we cannot infer from artesian wells the *rate* of increase of subterranean temperature, although they form a strong corroborative evidence to the other facts which have been adduced in establishing the reality of the increase of this warmth with the depth.

I have thought it necessary to enter into the preceding general details on terrestrial temperature, because it is probably intimately connected with the differences of temperature existing in thermal mineral waters, from a

<sup>1</sup> See Appendix, No. IV.



very little more than the mean atmospheric to even beyond the boiling point, under our ordinary barometric pressure. As before alluded to, our observations are still few in number, and most of them imperfect; but even in the present state of the inquiry, the following general principles seem to be well established:

1. On comparing the results obtained from different countries, there is considerable irregularity in the distribution of the earth's temperature at the surface. Although it decreases from the equator to the poles, this decrease is neither uniform under different meridians, nor is it dependent on that of the atmosphere.

2. It is a general law of the earth's constitution, that its heat increases with the distance from the surface. All the observations, whether on the air, the water, or the rock of subterranean cavities, concur in this general conclusion.

3. The rate of increase of the terrestrial temperature with the depth, may be assumed in round numbers at 45 feet for every degree of temperature by Fahrenheit's scale. So that in middle latitudes, at Edinburgh, for example, where the temperature at the surface is  $47^{\circ}.7$  F., we have only to descend to the depth of 7394 feet to find the solid strata of the crust of the earth at  $212^{\circ}$  F.

Having now discussed at some length the arguments on which is founded the doctrine of a progressive increase of temperature in the bowels of the earth, we must next proceed to examine the relations of the warmth of springs to ancient volcanic agency.

In the preceding chapter, we have seen the frequent, indeed almost constant, occurrence of thermal waters in the more or less immediate vicinity of rocks which most geologists now concur in tracing to a formerly existing volcanic action, when they cannot be associated directly with active volcanic processes. In such cases, it is true, every thing at the surface bespeaks repose and tranquillity,—would seem to indicate that if, at a former period, such subterranean fires did really exist, they have been wholly extinct for centuries. Such an idea, however, is

founded upon a very partial view of the phenomena in question. In many cases, cannot we trace the connecting link between these appearances, and the more obvious phenomena of active volcanism? Von Buch and Scrope have clearly shewn that a new volcano very seldom makes its eruption across secondary rocks; but this event almost invariably happens in those bearing undoubted marks of a previously existing igneous agency, such as basalt or trachyte, or in granite and its congeneric species. We are, therefore, constrained to admit the intimate connexion between these phenomena, and that at a greater or less depth, these ancient volcanic rocks retain their fluid state, or are in communication with the focus of modern volcanic agency, by fissures and rents in the crust of the globe, thereby furnishing an obvious and inexhaustible supply of caloric to the hot springs in their neighbourhood. On theoretical grounds, we might be led to infer the existence of an intense heat beneath these masses. The whole tribe of basalts, clinkstones, and trachytes, are well known to be very bad conductors of caloric ever since the observations of Dolomieu. V. Hoff<sup>1</sup> maintains that the reverse must be the case, in consequence of the compactness and density that must be possessed by the interior strata of the earth, from their great specific gravity. But the well known observations of Monticelli and Covelli<sup>2</sup>, who found, on the 15th January 1822, a layer of snow remain unmelted on Vesuvius to the depth of a foot and a half, after an eruption had continued for two days; and on another occasion were able, without inconvenience, to keep the naked hand in contact with the margin of a lava stream, the centre of which was still in a red hot fluid state;—are sufficient to shew the very bad conducting power of these materials. When we reflect, too, on the enormous heat which these substances must have once possessed, and on the magnitude of the masses which were once in a fluid state, it is not at all unlikely or difficult to conceive, that though they have been subjected to the radia-

<sup>1</sup> Bemerkungen über Karlsbad, p. 33, 1825.—<sup>2</sup> Storia dei Fenomeni del Vesuvio.

tion, or have rather been the conductors, of subterranean caloric for at least 6000 years, these rocky masses still retain, at no great depth beneath the earth's surface, the heat originally generated by primeval volcanism, although all active operations should have now ceased to exist.

Although, from these considerations, it is quite possible that the heat of many thermal waters may be derived from long extinguished igneous masses, situated deep in the crust of the earth; for if they are of considerable magnitude, and at a great depth, the time which has elapsed since the establishment of the present order of things can be but a small portion of that which would be required for the entire cooling of the igneous focus; yet nothing prevents us supposing volcanic action to be still in full activity below hot springs, and viewing them, with V. Hoff<sup>1</sup>, as products of the very same processes which produce volcanic eruptions and earthquakes. The connexion which subsists on many occasions between them and earthquakes (p. 210), as well as the substances which chiefly enter into their composition being the same which are discharged from the craters of volcanoes, would seem to point at the same conclusion.

On many occasions the temperature of springs undergoes a remarkable diminution as we recede from these rocks. This is the case in the Pyrenees (p. 187), and the Pennine Alps (p. 192).

Lastly, it remains for us to trace the connexion of the temperature of warm springs with modern volcanic operations. Here it is superfluous to enter into any minuteness of detail, where every thing is more cognisable by the senses, and where we have, in most cases, ocular demonstration of their origin. I shall, therefore, merely add a few considerations in illustration of the facts and doctrines which have been imperfectly delivered in the foregoing pages.

It is highly probable that volcanic eruptions owe their origin to a very simple cause, to the elastic force of aqueous vapours, which propel upwards through deep fissures

<sup>1</sup> Geschichte der Veränderungen der Erdoberfläche, ii. 89.



the fluid metals, alkalis, and earths, which consolidate into lava streams. That they are, as it were, intermittent springs of a peculiar class, by means of which the caloric of the interior of the earth makes its way into outer space. That but for the tendency of every eruption to terminate itself by the congelation of the lava within the crater, and the accumulation of ashes, sand, and slags, volcanoes would continue in a state of permanent eruption, or to speak more correctly, would serve as the permanent spiracles for the unceasing discharge of aqueous vapour. After the cessation of an eruption, the volcano passes into the state of a solfatar, which is nothing else than the constant discharge of acid and aqueous vapours, or hot springs, from the now congealed mass of lava, or fissures in the strata through which it has passed in its way to the surface. This state of a solfatar may continue for centuries, either till the reaccumulation of vapour gives rise to another eruption, or till the gradual cooling of the fluid focus diminishes the discharge of vapour and acid gases. The solfatar of Pozzuoli has discharged vapours ever since the times of Strabo. The hot springs, however, in the vicinity may still continue after the extinction of the solfatar, provided the water continues to traverse its former channels, which are still heated by the proximity of the volcanic focus, and may thus be the only historical document of the former existence of a volcanic eruption. In time, the temperature, and also the mineral impregnation of these springs, must diminish, in consequence of the continual recession of the active focus, till at last they resemble ordinary springs, which manifest no signs of having been formerly connected with a volcano at all.

If this is the history of warm springs, a gradual diminution in temperature and impregnation should be observable in the lapse of centuries. The constancy of their temperature might only arise from the excessive slowness of the cooling of their focus, from the causes above stated. Perhaps at some former epoch the water has been much hotter, but has gradually sunk to its present point. The time, however, which must have elapsed

since they attained the boiling point, is enormous, if their rate of decrease has not been formerly more rapid than at present. But from the very bad conducting power of the walls, it is not improbable that the time which has elapsed bears to the diminution of temperature not an arithmetical, but something approaching to a geometrical progression. Becher found in 1770 the temperature of the Sprudel water  $165^{\circ}$  F., not more than what it is at present. And at Mont d'Or, the temperature of which is now  $110^{\circ}$ , there are the remains of a bath (the only one till 1819), which shew that these waters were used for bathing in the time of Julius Cæsar, about 2000 years ago. Now this is about the highest temperature which the human body is capable of sustaining, so that the water could hardly have diminished sensibly in temperature during this long period of years. But if the diminution is supposed not more than one-fourth of a degree of Fahrenheit in a century, the cooling would not be discoverable even in this time, although it might latterly fall to the mean temperature of the place. If the warmth of thermal springs depends upon chemical processes in the interior of the earth, it must be subject with these to material changes, agreeably to what we observe in active volcanoes.

If there be any truth in these reflections, hot springs must be regarded as in fact true solfataras,—solfataras of an age anterior to all the historical records of our species, the remnants of a volcanism which raged at some period previous to the deposition of the tertiary or diluvial formations. The undiminished activity of their emergence ever since they have been subjected to our observation, is not to be wondered at. Have not Pozzuoli and the Phlegræan fields continued in the state of a solfataras for thousands of years? There is even evidence, as we have seen, for supposing the hot springs of Iceland, of Hungary, Italy, and many other countries, to have formerly possessed a much greater activity, and to have played a no insignificant part in the geological changes which have modified the physiognomy of the globe;—nay more, that at a period no less certain, though

it may be remote, the Geysers themselves will cease to be projected from its interior.

Before concluding the subject of the warmth of springs, the question naturally suggests itself, that of the three sources which have been enumerated (p. 296), what is to be considered as of most influence in any individual spring, or group of springs? It is sufficiently obvious that the caloric must be derived from one or other of these sources, but it is impossible to assign the share borne by each of them. Berzelius supposes that the tepid, weakly saline, and slightly sulphureous springs which issue from granite, such as those in the Pyrenees, those of Baden in Switzerland, and also at Bath and Clifton in this country, may derive their warmth from the first cause, from the general subterranean heat, and have their origin at a great depth. It is probable, however, that all the causes co-operate with regard to most springs. The transition between springs which owe their temperature to active and to extinct volcanism, is obvious. And may not the existence of a general subterranean warmth set a limit to the cooling dependent upon extinct volcanism, and be one of the causes of the permanence in the temperature of many warm springs remote from active volcanoes?

## SECTION IV.

### ORIGIN OF THE INGREDIENTS OF MINERAL SPRINGS.

It has been already hinted, that in all reasonings upon this subject, we are bound to assume our being acquainted with all the elements of bodies, and with all the laws which these elements obey in their reciprocal action on one another. If some theories regarding the internal constitution of the earth be admitted, we cannot argue upon such assumptions at all; in fact, we must remain stationary, and reject all inquiry upon the matter, upon the possibility of elements existing in the earth's



interior, which may exert an unknown but all-powerful influence upon the processes which are there carried on. The influence of *heat* and *pressure* will alter in degree, but not in kind, the results which can be obtained in our chemical laboratories. This alteration, although it may effect a vast change in the products which appear at the surface of the earth, and may entirely preclude the possibility of artificial imitation, will not impede our analysis of the due weight to be ascribed to these two agents in the formation of mineral springs.

Many circumstances lead us to consider the formation of mineral waters, as consisting in a simple process of solution and lixiviation; or that, in the words of Pliny, “*Tales sunt aquæ, qualis terra per quam fluunt*<sup>1</sup>,” taking this phrase in its largest and most general sense. The ingredients which they contain in most abundance, constitute for the most part great masses in the solid strata of the earth’s crust, as far as it is open to our inspection, or our knowledge of its internal composition is extended by the phenomena of volcanic eruptions. These ingredients exist in either exactly the same combinations as those in which they are found in the bowels of the earth, or with such variations in the disposition of their elements, as are entirely accordant with the known laws of combination. This maxim will hold true whether we adopt with Bischof<sup>2</sup> exclusively the theory of lixiviation, or with Stiff<sup>3</sup> that of sublimation, for in either case the water merely dissolves the substances with which it comes in contact in its subterranean channels, whether these are in chemical or mechanical union with the rocky strata forming the walls of these channels, in the form of sublimations lining the fissures, and derived from the volcanic focus; or whether they compose great solid masses ready formed in the mass of the rock formations. But it appears to me that neither of these three methods can be considered as presiding exclusively over the impregnation of mineral waters with their different solid and gaseous ingredients, whether it be *lixivi-*

<sup>1</sup> Histor. Natural. lib. xxxi. sect. 29.—<sup>2</sup> Vulkanische Mineral p. 312, &c.—<sup>3</sup> Geognost. Beschreib. Nassaus, p. 600, &c.

*violation, sublimation, or solution.* In many cases they all bear a share in the process ; and one substance may be derived from one source, and another from a second ; or in one class of mineral waters the one may be the dominant process, in a second another. It is this exclusive method of explaining the formation of mineral waters, as well as of many other natural phenomena, which has contributed to retard the science so materially, and has given rise to so many contradictory hypotheses. By attempting to reduce the varied energies of nature to some simple generality, more plausible to our understandings, we are often led to overlook circumstances which a more accurate examination and comparison of the local peculiarity of mineral waters would not fail to have disclosed.

Breislak, for instance, informs us<sup>1</sup> that by collecting and condensing the vapours which ascended from the Solfatara, he obtained daily about 3000 pounds of a mineral water, holding in solution sulphuretted hydrogen gas, muriate of ammonia, sulphate of alumina, and sulphate of iron. In this artificial experiment, we have an example of a mineral water formed by sublimation. Struve and Hermann<sup>2</sup> succeeded in the formation of mineral waters, holding in solution the muriate and sulphate of soda, and many other substances, by the simple action of boiling water, combined with high pressure, and a carbonic acid impregnation, upon the rocks which formed the walls of the channels of mineral waters. Here we have an example of a mineral water formed by lixiviation. And it is apparent to all, that common brine springs are nothing more than simple solutions of the masses of rock-salt, and saliferous clays and marls, which the water has traversed in its passage to the surface of the earth.

An eminent philosopher<sup>3</sup> has denied the possibility of our ever being able to explain how the water of springs becomes charged with its different foreign ingredients, because we do not find these existing ready formed in the bowels of the earth, as far as they have yet been ex-

<sup>1</sup> Travels in Campania, trans. by Reuss, 1802, p. 56.—<sup>2</sup> Struve Künstl. Nachbildung der Mineralq.—<sup>3</sup> Berzelius, Karlsbad, p. 60.

plored by the operations of miners, in such immense quantities as this would suppose. The different orifices of the Karlsbad Sprudel discharge annually about 13,000 tons of carbonate of soda, and 20,000 of the sulphate in the crystallized state<sup>1</sup>. But this quantity of alkali, although at first sight immense, is quite inconsiderable when compared with the mass which enters into the composition of the different feldspathic rocks, which are generally found in the vicinity of thermal springs, as will be seen when we come to treat of the origin of the soda of mineral waters. But this is going upon the supposition that they are all formed exclusively by a simple process of solution, analogous to brine springs.

I imagine that a much more important difference in the mode of origin of the ingredients of mineral springs, consists in their being ascribed to a *local* or to a *general* cause.

It is a remarkable fact, that in a very large proportion of mineral waters, and these by far the most important, the ingredients are identically the same with those discharged from the interior of the earth by volcanic eruptions, or found in fissures of the crater and lava masses in the form of sublimations. Such are muriatic acid, sulphur combined with oxygen or hydrogen, carbonic acid or nitrogen among the gaseous matters; and among the fixed, muriate of soda, muriate and sulphate of lime, sulphur, iron, &c. This includes the whole of the great division of thermal waters, whether they rise in the vicinity of active volcanoes, of extinct volcanic products, or of primitive rocks; as also the interesting and important divisions of acidulous and alkaline cold springs. Uniformity and constancy of impregnation are the most characteristic features of this great division, the different members of which are linked together by insensible gradations into one uninterrupted series. A second class derive their mineral ingredients, gaseous and fixed, from an entirely different source. They are mere local products of certain strata, holding a comparatively superficial place in the great geognostic series, and vary with

<sup>1</sup> Gilbert in his *Annalen der Physik*, lxxiv. 200.



the localities where they are produced. They are subject to changes dependent on external influences, whether of temperature, dryness and moisture, secular variations, &c. Many of these impregnating substances are the same as in the preceding class, so that it may sometimes be difficult to distinguish them at first sight by a simple chemical analysis; but it is here that an attentive examination of their geognostic and geographic positions is rendered available for the determination of their true nature, for in this they differ entirely from those which owe their origin to a more general cause. Generally, too, they are isolated, while the others are disposed in systems, groups or chains, as has been discussed more at large in my sketch of the geographic distribution of mineral waters. They are almost invariably cold, but this I would not cite as a distinguishing feature, because temperature, considered absolutely, is a mere accidental circumstance, probably dependent upon the length, nature, &c. of their subterranean channels.

With these preliminary remarks let us now proceed to the proper subject of this section, to trace the origin of the different substances which impregnate mineral waters; and of these,

*Carbonic acid* claims the first place, both from its great abundance and from the important influence which it exerts upon many of the other constituents.

We have formerly seen the intimate connexion between carbonic acid exhalations and volcanic products, whether the gas is united to water, or escapes from the earth in its free state. Having traced it to this origin, we might stop in our inquiry, but the question naturally suggests itself, whence is derived this great quantity of gas? I have already, when combating the pseudo-volcanic origin of springs, shewn the impossibility of its being evolved from the combustion of coal, or formed by the direct union of its elements.

It can only therefore be the product of the decomposition of some one or other of its natural combinations. But what salt containing this acid exists in sufficient quantity to afford such continued streams of it for so many cen-

turies, from every point of the surface of the globe? Carbonate of lime or common limestone, alone seems to be capable of fulfilling this condition. Second only to silica in being the most abundant of the rocky masses of the earth's crust, the range of its geognostical distribution extends from the newest tertiary deposits throughout the descending series, to the oldest primitive rocks. In the latter its beds are often of great extent. Nay, further, there are grounds for supposing its mass to be even still greater below the earth's surface, than is evident on its exterior. Among the numerous fragments of the disrupted strata discharged by volcanoes in a state very little altered by fire, there are none so common as fragments of limestone. Of the many instances on record, I may merely cite the observations of V. Humboldt on the volcano of Purace, in the Andes of Popayan, and those of Monticelli on the great eruption of Vesuvius in 1822. The carbonates of soda, magnesia, or of the metals, do exist, it is true, in considerable quantities, but they either do not form distinct beds, being chemically combined with the other constituents of rocks, or their geognostic distribution does not extend to the fundamental rocks in or below which is certainly the focus of the operations which generate carbonic acid. Neither can their quantity, however great, be once compared with that of limestone, and it is doubtful if it is adequate for the maintenance of so considerable a supply of this gas.

How, then, is the carbonic acid evolved from its union with lime? Is it by a powerful affinity of its base for some other acid? Or is it by a process of calcination produced by the intense heat which we have already seen to exist in the earth's interior. The determination of these questions is a problem of no ordinary difficulty. Perhaps we may reach an approximation.

What acids can we consider as adequate for the decomposition of the limestone? These must evidently be either the sulphuric or the muriatic, which seem to play an important part in volcanic eruptions. Sulphur is evidently necessary for the formation of sulphuric

acid. Now this mineral is almost entirely the product of volcanic operations, at least in any considerable quantity. It is true that beds of it associated with gypsum have been discovered in dolomite limestone connected with mica-slate, in the valley of Canaria, on the southern side of the Alps of St Gothard ; and more lately, masses of considerable extent have been discovered imbedded in quartz, also subordinate to mica-slate, in the mountain of Ticsan, between Quito and Cuença, in South America, at an elevation of nearly 8000 feet above the sea ; as also in the chloritic quartz of Brazil <sup>1</sup>. But these cases are rare ; they are local peculiarities, and form exceptions to the general rule. Sulphur is one of the most abundant sublimations in the crevices and fissures of every volcanic crater, and must therefore exist in its elementary state, deep in the recesses of the earth. In equinoctial America, it abounds in the trachytic porphyries and clays of igneous origin. It would perhaps be difficult to supply oxygen ; but, even admitting its acidification, would not the same action ensue which, on a smaller scale, we observe in our chemical experiments ? The limestone would soon become covered with an impenetrable crust of sulphate of lime, which would put a spontaneous termination to the further disengagement of carbonic acid.

There is no doubt that gypsum is found frequently in situations where it might in all probability be formed by the action of sulphuric acid on limestone, giving rise to the disengagement of carbonic acid. It has been found among the ejections of Vesuvius, and of the volcano of Namafial in Iceland <sup>2</sup> ; and its geognostic position generally is almost constantly in limestone districts, each of the limestone formations superior to the old red sandstone containing its subordinate gypsum deposits. Przysanowski has shewn <sup>3</sup> that in Italy, gypsum is always found near the active volcanoes of Vesuvius, Stromboli, or Etna ; the extinct volcanoes of Ischia and the

<sup>1</sup> *Humboldt*, *Gisement des Roches*, p. 73, 90, 91, 252.—<sup>2</sup> *Breislak*, *Manual of Geology*, iii. 533.—<sup>3</sup> *Ursprung der Vulkane in Italien*, 1822.



Monte Nuovo ; or in those districts of the Roman territory which indicate by their slags, &c. the existence of a former igneous agency, such as Valentino, Viterbo, Frascati, and Monte Rossi. In the volcanic districts of central France, gypsum is generally found accompanying the freshwater limestone. And, lastly, V. Buch has endeavoured to demonstrate that it is very commonly found in the vicinity of limestone, which has been changed by some former action of heat <sup>1</sup>.

Muriatic acid is another very common product of volcanoes, which might liberate the carbonic acid from its union with lime ; but it is improbable that its quantity is sufficient for the saturation of so large a mass of limestone. Muriate of lime is certainly one of the products of Vesuvius, when it can only have arisen from the decomposition of limestone masses in the interior of the earth. But this salt is never found in a solid state in the crust of the earth ; and, indeed, its deliquescent nature precludes it from existing in this state. Being found, however, in solution in many mineral waters, can it be derived from this source ? The same remarks apply to dolomite limestone and the muriate of magnesia.

Calcination is our last resource for the evolution of carbonic acid from limestone, and this is probably the most universal agent in the production of the gas. It has at least the advantage of simplicity in its operation. For we are perhaps incapable of fully estimating the reaction which the different natural combinations of carbonic acid and lime exert on one another, and on other bodies, in the way of mutual decomposition in the bowels of the earth. Berzelius, indeed, doubts the possibility of intense heat causing the continued disengagement of this gas from a mass of limestone, supposing that its action would cease after having penetrated to the depth of two or three fathoms, from the very bad conducting power of such stony substances. But this is supposing, as Bischof correctly observes, that the mass of limestone would retain its compacity and cohesion when subjected

<sup>1</sup> *Leonhard*, Mineralog. Taschenbuch, xviii. 471.

to this intense heat. This, however, would very far from be the case, as we have an opportunity of observing every day in our artificial lime-works. When exposed even to a very moderate degree of heat, the rock cracks in different directions, and separates into fragments, which fall down into the red hot focus. The disintegrating effects of the heat will also be much assisted by the aqueous vapour, and other elastic fluids, which probably bear their share in the process. It might be said that the carbonic acid, if disengaged in this way, should always appear at the surface possessing a high temperature; but there is no necessity for this being the case, if we consider the great depth at which these processes are carried on, and the length of the fissures by which it ascends to the surface. Calcination, too, will afford a better explanation of the enormous quantities of carbonate of lime held in solution by many springs, and deposited at the surface, when released from their great compression and high temperature. Upon the more complicated chemical process, which is that assumed by Bischof<sup>1</sup>, although we admit the disengagement of carbonic acid, all the lime will be retained in union with the other acids, only so much of the carbonate being decomposed as they are capable of saturating. Calcination will not only afford a large supply of acid, but will place a quantity of lime in the state most favourable for solution (its caustic state). For perhaps limestone, as it exists in nature, in union with many aluminous and siliceous compounds, is insoluble, or at least but slightly so, under any degree of compression, or at any temperature, at least within probable limits, even with the aid of free carbonic acid. But if the gas and caustic lime are presented to one another under favourable circumstances, they will exert a mutual reaction with the utmost facility.

If, as there are many reasons for supposing, the quiet and comparatively peaceful exhalation of carbonic from springs, is only a modification of what we see in volca-

<sup>1</sup> Vulkanische Mineralq. p. 263.

noes bursting forth with great violence, and even separating the solid crust of the earth, this view gains much additional weight, because, in the way of calcination, it will necessarily be disengaged with far greater force than by the slower action of chemical affinities. Besides, it is a matter of extreme doubt whether limestone could possibly exist in contact with masses which must be at an extreme degree of heat, without immediately undergoing decomposition in the way of calcination, long before the action of other strictly chemical agents could possibly have time to permeate the mass.

Some philosophers have considered the experiments of Sir H. Davy and Mr Faraday on the capability of carbonic acid being reduced from the gaseous to the fluid state by high compression, as of much importance in explaining the origin of acidulous springs, supposing it as probable that the acid only assumed its gaseous form on reaching the surface of the earth. But, of whatever importance this may be in regard to the form in which it exists in the interior of the earth, it does not affect the question of the source from which it is originally derived.

Such, then, is the source of the carbonic acid of true acidulous springs. In some cold springs, however, it is probably a mere local product of the decomposition of organic or carbonaceous substances. Its quantity is then comparatively inconsiderable, and it is generally associated either with sulphuretted hydrogen or the oxide of iron. These springs rise in the vicinity of deposits of coal, from an alluvial soil, in marshes or other situations where vegetable matters are in a state of decomposition. In this case, it may be the product of a simple process of fermentation and putrefaction, or of the decomposing agency of sulphuric and sulphurous acids, derived from the iron-pyrites which are very commonly disseminated in these localities. In tracing, however, the source of the carbonic acid which may happen to rise from a marshy soil, it is important to ascertain the nature of the fundamental rock, whether it is a mere alluvial sand or clay, a brown coal or lignite deposit, or an



older rock. From a neglect of this circumstance, many observers have been led into error regarding the carbonic acid which is disengaged so copiously from the marshes in the north-west of Bohemia, referring it to the organic matters in a state of decomposition, whereas it has been distinctly ascertained to issue from fissures in the subjacent granite.

*Sulphurous Acid, Sulphuric Acid, and Sulphuretted Hydrogen.* These are ingredients which we must refer both to a *general* and to a *local* origin. The two former may be considered together, as they pass so easily into each other by the contact of moisture and atmospheric air. Here, again, there are two methods in which these combinations may be formed,—either as a product of the union of their elements, sulphur with oxygen and hydrogen,—or as an educt from some sulphuret. The oxidation or combustion of sulphur is one of the most ascertained phenomena of volcanic action. Wherever it exists in volcanic districts, there are copious emanations of sulphurous acid gas; or, when in union with water, of sulphuric acid springs. The presence of oxygen, however, is necessary to sustain this combustion. If derived from the atmospheric air, the question recurs, What becomes of the azote? It might perhaps be answered, if we were acquainted with all the gases which issue from volcanoes into the atmosphere, azote is not improbably one of them; but of this we have no direct proof. In different parts of the world, we find what are called gas, air, or mud volcanoes, from which a great quantity of elastic vapours are discharged. Humboldt informs us, that the gas discharged from the *volcanitos* of Turbaco, near Carthagena in South America, is pure azote<sup>1</sup>. Spallanzani ascertained the presence of hydrogen in the gas of the Salsa della Maina in Modena; but whether the remainder was azote, we do not know. The same remark applies to the experiments of Parrot and Engelhardt on the air-volcanoes of the island of Ta-

<sup>1</sup> Atlas pittoresque, p. 239. He experimented on the gas with nitrous gas, and finding it to contain less than one-half per cent. of oxygen, he inferred the remainder to be azote.

man in the Crimea<sup>1</sup>. But Daubeny has ascertained positively that the gas discharged from Macaluba, near Girgenti in Sicily, consists of carbonic acid and carburetted hydrogen<sup>2</sup>. The formation of sulphuric acid in this way, from the atmospheric oxygen, is at least not so open to objection as that of carbonic acid from its elements, as in the latter case carbonic acid and other carburetted exhalations must always accompany the disengagement of azote. Can the oxygen be derived from the decomposition of water? Hydrogen is evolved in great quantities from many of the volcanic districts of Italy, either alone, or combined with sulphur.

The next source of the oxides of sulphur may be from the heating of sulphur along with metallic oxides. Oxide of iron, in the form of specular iron-ore, is one of the most common ingredients of lavas, and is found also in primitive rocks. In the focus of volcanic activity, its fusion with sulphur may give rise to the disengagement of sulphurous gas. The oxide of copper may, in a similar manner, be fused along with sulphur; for we find the muriate and the sulphate of this metal in the fissures of the lava of Vesuvius and other volcanoes, and the first of these salts is discharged in the gaseous form, from spiracles which are near a white heat. Manganese, in the form of sulphate and muriate, has also been recognised by Monticelli among the products of Vesuvius in 1822. And in smaller quantities are found arsenic, lead, and antimony, in the form of sulphurets or sulphates<sup>3</sup>.

In these general processes by which sulphuric acid is derived from the focus of volcanic action, it is constantly a product of the union of its elements, never an educt from any sulphate, unless we suppose the existence in the interior of the earth of some acid which is not decomposable by a red heat, as the phosphoric, boracic, &c. which may at a high temperature decompose the sulphates. Phosphate of lime or apatite is found in some

<sup>1</sup> *Breislak's Manual of Geology*, iii. 583. 594.—<sup>2</sup> On the Geology of Sicily in *Edin. Philos. Journ.* 1825, xiii. 257.—<sup>3</sup> *Bischof, Vulk Mineralq.* p. 289.

volcanic products, as at Vesuvius by Monticelli and Covelli, in basalt by Faujas St Fond, and at the Lake of Laach, which may have arisen from the decomposition of a sulphate of lime. Uncombined boracic acid is also a volcanic product, but no borate has been detected, which would have been the case if this acid decomposed any sulphate.

A local origin of the combinations of sulphur under consideration, is from the decomposition of a sulphuret by air and moisture. Iron-pyrites, although incapable of giving rise to such general effects as were once supposed to be derived from it as a cause, may very well be the source of the sulphuric acid, sulphuretted hydrogen, and sulphate of iron, of cold sulphureous and aluminous chalybeate waters. These generally emerge from strata in which this mineral is very abundantly disseminated, such as the coal-formations, secondary and alluvial clays. The lias clay, for instance, in England, contains much iron-pyrites, and it is the chief seat of the sulphureous waters of this country, and of those which abound in large quantities of the earthy sulphates. And the strongest aluminous chalybeates generally percolate through beds of clay ironstone, containing nodules of, or cemented together by, iron-pyrites. Many of the compact fetid limestones, which are the matrix of sulphureous springs, disengage a strong odour of sulphuretted hydrogen when dissolved in an acid, and there floats on the surface of the solution a black bituminous matter.

We possess no means of satisfactorily determining the source of the hydrogen of the springs impregnated with sulphuretted hydrogen which emerge from granite or from volcanic rocks. Is it from the decomposition of water? If so, it would furnish a strong corroborative proof of the access of the oceanic water being one of the chief agents in the maintaining the activity of volcanoes. A supply of oxygen would in this way be obtained, which would dispense with the necessity of having recourse to the atmosphere for the oxidation of the elements which we have been considering.



*Muriatic acid* is not only ejected from the craters of volcanoes, but is also a frequent ingredient of rocks of undoubted igneous origin. Spallanzani found it in pumice and obsidian from the island of Lipari, and in some of the lavas of Vesuvius, Etna, Stromboli, and the island of Vulcano<sup>1</sup>. The surface of the lava of Vesuvius of 1794 was, a few days after its eruption, covered with crystals of muriates of soda and ammonia. Olafsen and Povelsen found such a quantity of common salt discharged by some of the eruptions of Hecla, that several horses might be laden with it<sup>2</sup>. Different parts of the lavas of 1791 in the Isle of Bourbon, particularly the fissures, were found by Berth studded with crystals of salt. Von Buch found, after the eruption of Vesuvius in 1805, the fissures of the crater covered with a white salt, which Gay Lussac ascertained to be nearly pure muriate of soda. In such a situation, the salt must certainly have been sublimed, however inconceivable it may be upon chemical principles. Bischof endeavours to set aside the difficulty, by supposing it to have been formed by a double process: First, the condensation of elastic acid vapours, and then the extraction of the alkali from the solid bodies with which they came in contact<sup>3</sup>. In the year 1822, there was discharged from the crater of Vesuvius such an immense quantity of salt, that it supplied the culinary uses of the inhabitants of the adjoining villages for several days<sup>4</sup>. And the high-

<sup>1</sup> *Breislak*, Manual, iii. 97.—<sup>2</sup> Travels in Iceland, ii. 136.—<sup>3</sup> Vulkanische Mineralq. p. 280.

<sup>4</sup> The following view of the composition of this salt is given by Laugier (*Annal. de Chim.* xxxvi. 371.):

Soluble in cold water,	{	Muriate of soda,	.	.	62.9
		Muriate of Potash,	.	.	10.5
		Sulphate of Lime,	.	.	0.5
Soluble in hot water,	{	Sulphate of Lime,	.	.	0.6
		Sulphate of Soda,	.	.	1.2
		Silica,	.	.	11.5
Insoluble in water,	{	Oxide of Iron,	.	.	4.3
		Alumina,	.	.	3.5
		Lime,	.	.	1.3
		Water, and loss,	.	.	3.7
					100.0

ly interesting researches of Monticelli and Covelli shew, that common salt is by far the most abundant of all the saline products of Vesuvius, being found in the lavas, slags, pumices, sand, &c. Next to it are the sulphates of soda, lime, and potash, the muriates of potash and lime<sup>1</sup>.

It enters also as a constituent into ancient volcanic products. Vauquelin found 5.5 per cent. of muriatic acid in the porous domite of the Puy de Sarcouy in Auvergne<sup>2</sup>. Bischof has detected it, although not in a free state, in the trachyte and trachytic conglomerate of the Siebengebirge. Kennedy found 1 per cent. in the basalt of Staffa; Klaproth 0.01 in that of Libochowitz in Bohemia; and Bischof 0.085 in that of Oberwinter on the Rhine.

These examples are more than enough to shew the source of the exhalations of muriatic acid, and that it is formed by evolution from some muriate, not by the union of its elements, chlorine and hydrogen. Chlorine has never yet been detected among the emanations of volcanic activity. Muriatic acid may be separated from all its combinations in the interior of the earth by sulphuric acid, or by sulphur, with the aid of heat. Muriate of soda, or common salt, is the most probable of these combinations, which, for that purpose, may either form immense masses of rock-salt in primitive rocks, or be derived from the sea-water. In either case, the muriatic acid disengaged may appear at the surface of the earth, in its free state, or again enter into combination with the different bases it meets with in its progress to

<sup>1</sup> Storia del Vesuvio, p. 65.

<sup>2</sup> Annales du Musée, vi. 98. This rock consisted of

Muriatic acid,	.	.	.	}	5.5
Animal matter?	.	.	.		
Water,	.	.	.		
Iron,	.	.	.	}	2.5
Alumina,	.	.	.		
Magnesia,	.	.	.		
Silica,	.	.	.	.	91.5
					<hr/> 99.0

the surface, and form those salts which are so often found among the ejections of volcanoes. These considerations may suffice at present for the illustration of the mode of origin of the free muriatic acid. The sources of its compounds, such as the muriate of soda, &c. will come to be considered afterwards, although many of the points connected with this inquiry have been already anticipated in this place.

*Soda* is by far the most important of the solid constituents of springs, and will demand a somewhat detailed examination.

Soda, either in its free or carbonated state, is constantly an ingredient of volcanic rocks, ancient and modern, although in very different proportions. For the first distinct notice of this highly interesting fact, we are indebted to the distinguished chemist Klaproth, who saw all its importance with regard to many natural phenomena<sup>1</sup>. But, to the elaborate and comprehensive analysis of Professor Bischof, we are undoubtedly indebted for the exposition of its real importance, with regard to the origin of mineral waters. Clinkstone was found by Klaproth to contain 8.10 per cent. Basalt was found by the same chemist to contain 2.6; and by Kennedy 4 per cent. It was found by Descotils and Vauquelin in different quantities in obsidian. From 1.48 to 3.0 in pitchstone by Dumeril, Klaproth and Bergman. In pearlstone by Vauquelin, to the amount of 0.7. In pumice by Klaproth. In the lava of Etna by Kennedy, to the amount of 4 per cent. And in the Moya discharged from the volcanoes of South America, Klaproth found 2.5 per cent. Bischof extracted the alkali from the trachytic conglomerate of the environs of Bertrichbad, by the simple action of boiling water, and a still greater quantity by boiling nitric acid: it was associated with potash, and both existed in the rock in their caustic state. This conglomerate consisted chiefly of fragments of pumice.

Its quantity is much greater in the different simple

<sup>1</sup> Beitrage, iii. 143.



minerals which are found filling the amygdaloidal and drusy cavities of volcanic rocks. These principally belong to the zeolite family; and it amounts in some (sodalite) to even 25 per cent. Pure carbonate of soda occurs in many volcanic districts, in the form of sublimations or efflorescences; as at Vesuvius (Breislak), Etna (Dolomieu), Isle of Bourbon (Bory), Monte Nuovo, Teneriffe, Karlsbad, and Bilin in Bohemia (Reuss). And abundant efflorescences of a salt containing 12 per cent. of the alkali, have been found on the conglomerates of the valley of Brohl, near Tonnistein, in the district of the Lake of Laach, associated with a large proportion of potash<sup>1</sup>.

What is now more natural than to derive the soda of mineral waters from those rocks which constitute such enormous masses in their environs? A very simple calculation is sufficient to shew, that the Donnersberg alone, the loftiest of the Bohemian Mittelgebirge, a cone of clinkstone 2500 feet in elevation, contains soda enough to supply the Karlsbad waters alone for more than 30,000 years<sup>2</sup>. But we need hardly have recourse

<sup>1</sup> This saline matter consists of

Sulphuric Acid,	.	.	8.68
Muriatic Acid,	.	.	6.71
Carbonic Acid,	.	.	20.84
Soda,	.	.	12.08
Potash,	.	.	51.69

---

100.00

(*Bischof*, Vulk. Mineralq. p. 242.)

<sup>2</sup> Supposing the sides of the Donnersberg inclined at an angle of 45°, which is far more than the truth, and that it is a perfect cone, the diameter of its base would be 5000 feet, and consequently its superficies  $\frac{3.14}{4} \cdot 5000^2 = 19625000$  square feet. Its cubic contents will

be  $19625000 \cdot \frac{2500}{3} = 16354.166666$  cubic feet. The specific gravity of clinkstone is 2.575; therefore the weight of the Donnersberg would be  $16354.166666 \cdot 2.575 = 29478385.1546$  lb, assuming the cubic foot of water at 70 lb; and as clinkstone contains 8.1 per cent. of soda, the weight of soda in the Donnersberg would be 238774,921,865 lb, or about 119,387,460 tons. On dividing this sum by the quantity of soda discharged annually from the Sprudel, it will be found to be capable of maintaining the supply for 35394 years, supposing that 100 parts of crystallized carbonate = 22.26 pure soda; and 100 parts crystallized sulphate = 19.26 soda.

to such a calculation to prove the adequacy of this source to supply the soda of mineral waters. The proportion of alkali in these rocks once known (4 to 10 per cent.), the geologist need only cast a glance upon the extent of these rocky masses to be convinced of the inexhaustible stores which they contain. What agent could exhaust the alkaline contents of the vast trachytic domes of Auvergne and the Andes, or of the felspar in their subjacent granite rocks<sup>1</sup>, which are peculiarly the seat of mineral waters largely impregnated with soda?

But how is the soda extracted from these rocks, so as to be rendered available for the impregnation of mineral waters? Whatever be the nature of its union with the other constituents of the rocks, whether mechanical mixture or chemical combination, it cannot be extracted by the simple action of water on the undecomposed rock, although in certain circumstances, as we shall afterwards see, it separates spontaneously with the utmost facility. Acid vapours, however, or water charged with them, have been fully proved to be capable of extracting the alkali, by the experiments of Struve, even when the amount of acidity is but small, whether from the feeble affinities of a particular acid, or its high state of dilution. Have we not seen that carbonic acid exhalations are among the most universal concomitants of such feldspathic rocks? They may certainly then extract the alkaline matter from the rock, either directly *via sicca*, or by lixiviation along with water, even when under the ordinary atmospheric pressure; and of course still more readily if aided, as it is probable that they most generally are, by high pressure, and an elevation of temperature. Sulphuric and muriatic acids will act in the same

<sup>1</sup> It might be urged against the extension of these views to granite, that potash is a rare ingredient in springs, although a very great proportion, especially of the thermal class, emerge from this rock, the most abundant mineral of which, *common* felspar, contains this alkali instead of soda. But it should be remembered, that *compact* felspar very frequently supplies the place of the common crystalline variety, where soda is the alkaline ingredient. Perhaps too many of the springs which have been supposed to contain soda owe their alkaline qualities to potash? See p. 351.

way with still greater power ; although not so generally diffused in the form of free exhalations as carbonic acid, their disengagement is continual from volcanoes, solfataras, and many extinct craters. This certainly is a much more rational way of explaining the origin of the carbonate, sulphate, and muriate of soda in mineral waters, than by supposing the existence of immense ready formed masses of soda deep in the interior of the earth.

This theory has been objected to by Stiff, upon the ground of the uniformity in the impregnation of mineral waters through a long course of years. If the alkali was extracted by acid vapours or solutions ascending through fissures in the rocks, their solvent power could only act on the walls of the channels, which would become gradually exhausted of their alkaline matter, the quantity of which in springs would gradually diminish and finally disappear. The same effects would ensue to whatever distance from the immediate channels we supposed the action of the lixivium to penetrate, only that, in this case, the changes in the springs would be much slower. But this objection is of no weight if we consider for a moment the utter disproportion between the alkaline ingredients of even the most abundant springs to the enormous mass contained in the rocks in question, which, even supposing the lixiviation to extend to a very small distance, would be far more than sufficient to maintain a uniform supply for a period infinitely greater than that which has elapsed since mineral waters have been subjected to any thing like accurate analysis. Besides, the term uniformity of impregnation is merely relative, in reference to historical epochs it may be so (even this remains to be proved) ; but are we justified in assuming it to be the case in the long period which has elapsed since the first flowing of many springs, ascending even probably far into geological epochs ? What should even prevent the free access of the lixivium to every part of the rocky masses ? This, it is said, would entail the decomposition of great portions of the rocky crust of the globe, and would cause great sinkings at its surface ; and “ a basalt or clinkstone without its soda is no more



basalt or clinkstone<sup>1</sup>." Were this even the case, the results would be insignificant. The whole mass of saline matter which has been discharged from the Karlsbad Sprudel for the five centuries which have elapsed since its first discovery, would not form a cube of 410 feet; and the salt bed of Wieliezka alone, which have been excavated in a space 6000 feet long, 2000 broad, and 800 deep, is calculated by Von Hoff to have yielded a mass of salt capable of supplying the same springs for 56,000 years<sup>2</sup>. In calculating the relations of space and time to natural phenomena, how apt are we to be deceived in the employment of our artificial measures!

While I would argue the possibility and perfect probability of the soda of springs being derived from this source; notwithstanding its perfect adequacy for that purpose, I am far from asserting that it is derived exclusively from feldspathic rocks in the way of lixiviation. There are other methods which it remains for us to consider.

In many situations the alkaline contents of feldspathic rocks separate spontaneously, and present themselves in the state ready for solution either by acid vapours or simple waters. The saline efflorescence of the Brohl conglomerate has been already noticed (p. 338).

The results of *efflorescence* must be carefully distinguished from sublimation. It is the process by which a substance already existing in the interior of a rock appears on the surface as a distinct substance. Thus lavas, slags, pumice, &c. are all impregnated more or less with saline matter, which effloresces on the surface when they are placed in certain favourable circumstances. I shall not stop to inquire into the *rationale* of the process, whether it be owing to a simple capillary action, or to the movements depending upon the operation of affinity; suffice it to say, that the two conditions which seem most to favour its occurrence are,—an elevated temperature, or a diminished temperature accompanied with the access of moisture. The salts which effloresce on

<sup>1</sup> *Stiff* in Edin. New Phil. Journ., April 1832.—<sup>2</sup> *V. Hoff*, Karlsbad, p. 95.

the surface of rocks may exist in their substance either in a caustic state, and first become acidified on reaching the surface, or they may be already neutral in the rock itself.

Monticelli and Covelli found many effloresced products at Vesuvius, the Phlegræan fields, and the Solfatara, both in fissures which were above the boiling temperature, and in caverns which did not exceed the ordinary temperature of the atmosphere, but were bedewed with moisture. The principal salts observed were: the muriates of soda, potash, iron, copper; sulphates of potash, soda, lime, iron, copper; alum; and sal ammoniac.

Closely allied to efflorescence is the well known process of *weathering* observed in many rocks, from the simple action of the atmosphere. Of the four ingredients in the atmosphere, oxygen, azote, water, and carbonic acid, the two latter are the chief agents in this process, either alone or in combination. We are perhaps incapable of explaining satisfactorily the action of water alone, whether it simply lixiviates the alkalis existing in the rock, or acts by its affinity in the formation of crystallized salts. More influence is in all probability due to the carbonic acid. Although its quantity in the atmosphere is proportionally small, it is fully capable of overcoming the attraction of the alkali for silica or alumina; as, although a weak acid, it stands much higher in the electro-negative scale than these substances. All those rocks which contain soda or potash weather with greater or less facility. The feldspathic rocks lose the greater part of their alkali, and pass into the state of porcelain earth or kaolin<sup>1</sup>. We can easily conceive what a rich source of alkali this furnishes for springs, and of course it will be greatly facilitated when, as is generally the case, the percolating water contains more carbonic acid than what is simply derived from the atmosphere. A strong confirmation of this being, frequently at least, a subsidiary source of the alkali of

<sup>1</sup> *Berthier* (Annal. de Chim. xxiv. 108), found in five specimens of kaolin, derived from the decomposition of felspar, the quantity of potash to vary from 0.01 to 0.082.

springs, is the decomposed state in which are often found the feldspathic rocks which form the walls and fissures of mineral waters, much more than what can be owing to the ordinary effects of atmospheric agents. This is seen at Karlsbad, Königswart, Wiesbaden, Ems, Mont d'Or, St Nectaire, the Pyrenean thermals, &c., and generally in the vicinity of all those which exhale much carbonic acid from their environs. Sometimes, though much more rarely, the decomposition may be the effect of the reaction of the alkaline contents of the springs upon the siliceous matters of the rocks.

Intimately connected with the explication of the sources of the soda of springs, both in its carbonated state, but more especially of the muriate and sulphate, are the phenomena of the *natron lakes* found in different parts of the globe. As far as we are acquainted with the localities of this mineral product, the circumstances under which it is found are the same in all situations, whether in Hungary, the Steppes of the Black Sea and the Caspian, Egypt, Arabia, Persia, Asia Minor, India, Tibet, China, Siberia, or Mexico.

The carbonate of soda is found, on the evaporation of the water of the lakes or marshes, forming efflorescences of greater or less abundance in the midst of sands mixed with marls and clays of extensive plains, steppes or deserts. It is never pure, but always mixed with a certain quantity of the muriate, and sometimes the sulphate. The clays and sands generally effervesce with acids, when the alkali is removed by lixiviation; in the plains of Debretzin in Hungary, Beudant<sup>1</sup> found them to contain six per cent. of the carbonate of lime. It is a remarkable circumstance, that in Hungary, the nearest point where they have been found, and where their relations have been studied with more accuracy than elsewhere, we find in the middle of the plain salt-marshes, and in the hills which surround them salt-springs in greater or less numbers, and, lastly, we arrive at the rock-salt deposits, explored for economical purposes. From the

<sup>1</sup> Voyage en Hongrie, ii. 336 ; iii. 237.



little information possessed of the natron lakes of other countries, it is not improbable that their relations are similar; for, on tracing the plains which contain the lakes, there are always found considerable deposits of rock-salt where the caravans derive a supply of this article.

With regard to the mode of formation of the natron deposits, muriate of soda then is the only other salt found in any great quantity in the plains, and capable of maintaining an unceasing renewal of the alkali removed for the purposes of commerce. Rückert, it is true, imagined<sup>1</sup> that it existed ready formed in the sands and clays. This is certainly the most natural supposition, but it is supported by no direct observation. Nowhere have there been detected subterranean deposits of the carbonate of soda, either in salt mines or in the evaporations of sea water; it only exists in efflorescences at the surface of the soil. How, then, is it formed from the muriates? Berthollet was the first who called the attention of geologists and chemists to this question. Reasoning upon his theory of affinities, and upon the ideas which the phenomena of the extraction of salt-petre suggested, he considered it to be owing to the reciprocal action of the muriate of soda and carbonate of lime; a hypothesis which he was enabled fully to verify upon the inspection of the natron lakes of Egypt. These lakes are situated in the midst of a limestone formation, which pierces the sands in different situations. Beds of gypsum are also found, which probably belong to salt deposits in the vicinity. Limestone is here the only substance within reach of the muriate of soda; but in ordinary circumstances it is unable to decompose this salt. It, however, becomes capable of doing so when the salt water penetrates its pores. The great relative mass of the carbonate of lime here augments the intensity of its chemical action; and the lime unites with a portion of the muriatic acid, and the soda with a portion of the carbonic.

The vicinity of great limestone masses is not peculiar

<sup>1</sup> Crell's Chemical Annals, Nos. 2, 3, and 6, 1792; and Journal des Mines, No. 2, p: 117.

to the Egyptian lakes. The richest of the natron lakes of Hungary are at the eastern extremity of the central plains, at a short distance from the foot of the limestone mountains which constitute the *Vorgebirge* of Transylvania, in the midst of which are also considerable salt deposits. And in the plains of Oedenburg, farther to the west, there rise above the plain, in the vicinity of the lakes, deposits of *calcaire grossier* and other tertiary limestones.

Sulphate of soda, which is generally found in smaller quantity, accompanying salt and alkaline lakes, may very probably be formed in the same way from the gypsum which generally accompanies saliferous deposits. But this salt in saline springs may be formed from muriate of soda in another way. Iron-pyrites and aluminate are often disseminated in considerable quantities in the saliferous clays, as well as in the coal formation. They would communicate sulphuric acid if solutions of rock-salt penetrated through them during the process of their vitriolization: this would be particularly the case with the sulphate of alumina, which parts with its acid so very easily. It may also be easily conceived that this will be a fertile source of the sulphuretted hydrogen often given off by salt springs. Upon the same principle may be explained the presence of the salts of iron so frequently associated with these springs.

The preceding observations upon salt springs and salt lakes naturally lead to an interesting geological question, viz. the origin of the great saliferous deposits found in the different secondary formations. Salt springs are in every case derived from salt deposits; but it has been seen, under the head of the geognostic position of these springs, that we cannot infer the formation to which they owe their origin, from the rocks out of which they issue being found to emerge even from those which have not been hitherto found saliferous at all. Neither does a high degree of saltiness prove their proximity to their parent beds. Owing doubtless to the complicated circulation of aqueous fluid in the interior of the globe, the saltiest springs might be even removed to the great-

est distance from the spot where the water takes up its saline matter.

It is a matter of considerable difficulty to assign the precise age of the salt formations of the different sedimentary rocks, or, in other words, their geognostic position in the grand series. As far as the investigations of geologists have yet extended, they seem to be found,—in the magnesian limestone, as in the country of Salzburg; in the variegated sandstone, as in England; in the plastic clay, as at Wielickza; at the surface of the soil, as in the arid plains of Africa, Persia, the deserts of Lower Peru, and the steppes of Buenos Ayres. Von Buch has made the curious observation<sup>1</sup>, that in Europe the richness of the saliferous deposits diminishes with their elevation above the surface of the present ocean. The following is the gradation: England, the richest, at 192 feet; Wielickza, at 1020 feet; Bex in Switzerland, 1400; Berchtolsgraden, 2110; Aussee, 2880; Ischl, 3170; Hallein, 3960; Hallstadt, 4220; Arbonne in Savoy, 4800? Halle in the Tyrol, 5116. This rule, however, is by no means general; Humboldt found very rich saline masses both on the coast of Peru (at Huaura), and at an elevation of 8950 feet in the Cordilleras of New Grenada (at Zipaquira). The immense rock-salt masses in the vast plains to the north-east of Mexico, for the knowledge of which we are indebted to Jefferson, are said to be situated in the coal formation, but of this farther accounts would be desirable: it is not improbable that their position is analogous to the Gallician deposits, which repose on the coal formation, but more probably belong to the newer lignite formation, with which they are covered.

Can we assign the same age to the masses of rock-salt found at the surface of the sandy deserts, and the salt lakes and marshes scattered in different parts of the globe, which latter seem to be in a state of progressive diminution, from the phenomena so well described by Pallas as observable in the basin of the Caspian, or the

<sup>1</sup> Poggendorff's *Annalen*, 1825, st. i.



great Asiatic depression? And are they both the remnants of the last irruption of the ocean upon our continents? As yet we are acquainted with the geognostic position of hardly any of the salt-masses which constitute, as it were, the last pellicles of the globe. But they would seem to be the prolongation of beds of the same nature which are found in the adjoining mountains, usually composed of limestone or other rocks known to be the matrix of salt, but which in the plains appear at the surface in consequence of the denudation of their cover of solid rock. Such seems to be the relation of the Egyptian deposits. In Hungary, we are informed by M. Beudant, that the matrix of salt found at the surface of the plains is a clay quite analogous to that which at Wielickza, and other salt-mines along the line of the Carpathians, are covered by a geognostic formation, —a mass of sand and sandstone no less than 1190 feet in thickness. But, in the plains, this immense formation being altogether wanting, permits of the saliferous deposit appearing at the surface, and yet retaining its ordinary position; resting in all probability on the coal sandstones of the Carpathians, which are prolonged under the plain. The want of ravines, water-courses, or other natural sections, has prevented the verification of this last supposition. It could only be resolved by sinking a shaft in the midst of the salt-deposits of the plain; or by exploring more fully the central districts of Transylvania, where the numerous salt-works must present numerous facilities for the investigation of this interesting point of the geognosy of superposition.

If there be any foundation for these ideas, the age of these superficial rock deposits must be very different from that of the salt lakes and other similar formations resulting from the evaporation of water. The last are generally admitted to be the remains of the last epoch, when the dry land was submerged by the ocean. But the former would be of much older date with regard to the period of their deposition; they would be coeval with the salt beds found in the sedimentary rocks, notwithstanding their present position at the surface of the soil.

How they have attained this position, or been denuded of their superincumbent rocks, is a problem I will not attempt to solve. For that they were once covered by strata of greater or less solidity is absolutely necessary for the stability of this hypothesis; otherwise the last cover of oceanic water would have dissolved them, and left not a vestige behind. Can their denudation have been owing to the catastrophe accompanying the retreat of the same oceanic water, of which we find the remains in the salt lakes of the great Asiatic depression? I am aware that it may be alleged these salt masses at the surface of the plains may be nothing else than the residuum of the evaporation of salt lakes. But why should we always find in the eminences surrounding these plains, salt springs issuing from a saliferous clay covered by a great geognostic formation? And, in the plains, this last formation to be wanting, while the clay and fundamental rock remain the same. To establish this hypothesis upon solid grounds, would require a thorough geognostic investigation of the fundamental rock of these saliferous plains, and of the structure and position in the great series of the nearest mountains.

Such is the position of the great saliferous masses; but we find partial formations in much older rocks. I allude to the important discovery by Charpentier, of an immense mass of anhydrous gypsum with disseminated rock-salt in the mines of Bex in Switzerland, which forms subordinate beds in greywacke, belonging, according to this geologist, and Von Buch, to the newest transition limestone<sup>1</sup>. The anhydrous state of this gypsum and muriate of soda seeming to preclude the idea of its having been deposited from an aqueous solution, it has been commonly admitted that here is an example of the origin of rock-salt by sublimation in the dry way, which could only have resulted from volcanic agency. The last of the eminent geognosts just named, even extends this igneous origin of rock-salt to the beds found in secondary rocks. There can be certainly no difficulty in

<sup>1</sup> Poggendorff's Annalen, iii. 75.

admitting the formation of rock-salt in this way, on considering the enormous quantities rejected from the bowels of the earth during many volcanic eruptions (p. 335). According to Cordier, the salt mountain of Cardona in Spain is also in transition-rocks; and Humboldt mentions the saliferous gypsum of Colancolan in the Peruvian Andes as occupying the same position: but whether in these situations the salt is anhydrous as at Bex, we are not informed. We are informed by Proust, upon the authority of Fernandez<sup>1</sup>, that the celebrated salt mines of Poza, near Burgos in Old Castile, are situated in the centre of a great crater, in which are found basalt, olivine, pumice, puzzolano, &c. And, lastly, Humboldt has found saliferous clays superposed on trachytic conglomerates at Ibarra, on the plateau of Quito, at an elevation of 7600 feet above the level of the ocean.

From these accumulated examples, are we not entitled to infer that many salt beds are originally of igneous origin by way of sublimation; and that many salt-springs are derived from the same source, either mediately through these beds, or immediately by direct ejection from the volcanic focus? I am inclined to suppose that the saline impregnation of thermal waters is, in by far the majority of cases, to be traced to the latter source. These springs seldom emerge from the great horizontal formations, usually the matrices of rock-salt, and the primitive and igneous rocks have not been hitherto discovered to contain this mineral in the ordinary form of beds, or in the hydrated state. Indeed, if the igneous origin of hot springs be at all a likely supposition, and the whole tenor of the recent observations of naturalists have brought it close to the borders of a demonstration, we cannot suppose the great rock-salt formations to be at all the source of saline thermal waters. The great new red sandstone and other analogous formations must have been a deposit from some ancient oceanic fluid. The aggregation of the particles of muriate of soda into tabular beds, instead of being equally diffused through

<sup>1</sup> Journal de Physique, lv. 457.



a formation which entirely owed its fluidity to its own solvent menstruum, must be regarded as a result of that unknown affinity which attracts substances of opposite electric habitudes, as, in short, a grand process of crystallization into the primitive form which this salt is on all occasions wont to assume. With regard to the origin of the torrents of salt water and masses of salt discharged from volcanoes, I formerly (p. 292) adduced a few of the grounds on which I would be inclined to derive it from the great mass of oceanic fluid.

If there be any truth in this idea on the origin of the most important of the ingredients of mineral and thermal springs of this peculiar class, they must be considered in the same light as volcanic eruptions, as constant products of the volcanic focus, the latter being its intermittent manifestations; or, in the words of Stiff, "Volcanic rocks and mineral springs do not stand to one another in the relation of cause and effect, but are the effects of one common cause,—of the vast central igneous focus<sup>1</sup>." So long as the gaseous products of this focus are retained by the pressure of the superincumbent rocky strata, their elastic force progressively increases till it becomes capable of rending asunder the solid crust of the globe, and of clearing for itself a passage into outer space. Should they, however, find a ready ascent through fissures already existing, such an accumulation of elastic force cannot take place, volcanic eruptions will not occur, and there will be substituted for them the permanent and peaceful ascent of mineral springs.

No difficulty presents itself in explaining the origin of the *Lime* and *Magnesia* impregnating mineral waters. Water impregnated with carbonic acid, or any of the other acids derived from the sources we have been considering, is well known to be capable of dissolving freely the carbonates of lime and magnesia. And when we consider the extensive distribution of these earths in the crust of the globe, we cannot be surprised that most mineral waters should contain them, and often in considerable quantity.

<sup>1</sup> Nassau, p. 593.

*Iron* need not detain us a moment. It is an abundant mineral in volcanic and sedimentary rocks, from which it is extracted by the same agents. I need not repeat that its proportional quantity is generally small, although of very general occurrence.

*Silica* has been already discussed sufficiently for our purpose at p. 260.

Before concluding the subject of the source of the ingredients of mineral waters, I may be allowed to make a few remarks upon their rarer ingredients,—the potash, iodine, bromine, lithion,\* phosphoric and fluoric acids, which, although insignificant in point of quantity, are not the least interesting of their impregnating minerals.

*Potash* we have seen to enter largely into those compositions of the saline efflorescences of those conglomerates, which consist chiefly of fragments of pumice. If, then, the impregnation of volcanic mineral springs is derived from similar feldspathic rocks, this alkali might be expected to be a much more common ingredient. But we cannot be surprised at its comparative rarity. It was first discovered to exist in mineral waters in 1806, by Berzelius, in his analysis of the springs of Adolfsberg and Porla in Sweden, where it is unaccompanied with the salts of soda. These waters probably issue from primitive rocks<sup>1</sup>, in which potash is an abundant constituent. It is not improbable, therefore, that, in many of the older analyses, soda has been taken for potash, and the latter quite overlooked. It probably exists in the Karlsbad water, having been discovered in some of its sinters; and it has been actually found in Teplitz and Königswart; and Bischof has also detected it in the Roisdorf waters. In all these localities it possesses the peculiarity, in common with soda, of being accompanied with abundant exhalations of carbonic acid, which probably separates it by a similar process of decomposition from the surrounding feldspathic rocks.

*Iodine* and *Bromine*, which Professor Daubeny has lately demonstrated to enter into the composition of nearly all the brine springs of England, are, as that geo-

<sup>1</sup> *Hausmann's Travels in Scandinavia*, ii. 371.

logist observes, interesting from their serving to identify the products of the ancient ocean, which deposited the great sedimentary formations, in the most minute points with those of the present.

*Lithion*, hitherto found only in the Karlsbad, Franzensbad, and Marienbad springs, is perhaps derived from the decomposition of a variety of mica; the lepidolite, occurring in granite, primitive limestone, and in magnetic ironstone beds subordinate to gneiss. This mineral has not, it is true, been yet discovered in the granite of the environs of these Bohemian springs. But it probably exists there, being found in the adjoining mountains of Moravia and Silesia.

Can the *fluoric acid* be derived from the fluates of lime and fluosilicates which have been of late years found in different varieties of mica found in granite and other primitive rocks?

*Phosphoric acid* may, in the same way, be derived from the decomposition of apatite (phosphate of lime). This mineral is found at the silver and lead mines of Joachimsthal, not far from Karlsbad.

It would be foreign to the system that I have endeavoured to follow in the present essay, to enter into consideration of the many hypotheses which have been proposed for the solution of the problem, What is the nature of the interior of the globe? And yet such a line of argument would not be altogether foreign to the science of mineral waters, whose relations have gradually become more extensive and interesting the deeper we have entered into their investigation,—more and more intimately allied with the physics of the earth.

It must be confessed that we possess very little that is certain or determinate upon the subject, notwithstanding the labours of the numerous mathematicians and naturalists who have applied the resources of their respective sciences towards its resolution. The determination of the specific gravity of the globe was a great point gained, as affording one fixed point from which we may advance; but further, I conceive, we have not proceeded.



Perhaps the most plausible of these hypotheses being that most accordant with those laws which are open to our inspection, is that which originated in the splendid discoveries of Davy, viewing the crust of the earth as the result of a grand process of oxidation. That its interior is chiefly composed of the bases of the earths which enter most abundantly into its constitution,—of silicium, calcium, aluminum, sodium,—the oxidation of which, a purely chemical process, gives rise to all the phenomena of volcanoes, hot springs, &c. Is the oxidation effected by the influx of water, or of atmospheric air? In the former case, hydrogen ought to be disengaged copiously from the earth's interior, alone or combined; in the latter, azote will be set free: the former is the more probable supposition, but both perhaps have their share in the process. Numerous objections, however, might be urged against this idea of the internal constitution of the globe. To select only one of these,—Is not the low specific gravity of these metals inconsistent with the mean density of the earth? \*

The theory of compression, recently brought forward by an eminent philosopher, may perhaps be demonstrated mathematically. But the exclusive method only can be employed, and such data do not furnish a solid basis of induction. We are utterly ignorant of the great changes which the physical forms and component parts of bodies undergo, when under the influence of such enormous pressure as the hypothesis presupposes. This may amount to a total change of constitution, even in the most diffusible and elastic of them all. Besides, does such a pressure really exist in the interior of the earth? or is it not counterbalanced by the cohesive force of its solid crust?

Or, in fine, shall we have recourse to the solvent menstruum of the primeval ocean, to explain the origin of springs, a remnant of which may exist in the interior of the earth possessing all its original properties?

All this is pure conjecture; we will never arrive at an ultimate fact, at a great first cause. The mind is forced to fall back from one supposition upon another

equally gratuitous, if not still more improbable, till it is compelled to pause, and to wonder by what steps it arrived at its present positions ; to rest satisfied with the imperfect range of its powers, with its subserviency to the dominion of the senses ; and to return to the well-known axiom of Verulam : “ *Homo naturæ minister et interpres tantum facit et intelligit, quantum de naturæ ordine re vel mente observaverit : nec amplius scit aut potest !*”

With this I shall conclude my Inquiry into the Natural History and Origin of Mineral and Thermal Springs, in which it is my hope that the limits of sound induction have not been overstepped. Imperfect it is, but this imperfection attaches also to the science it concerns. It is only within these very few years that this subject has engaged the attention of naturalists in a degree by any means proportioned to its merits ; nor in this, any more than in the other departments of nature, when closely investigated, have these researches been altogether unrewarded. Some new views have been disclosed regarding the structure of our globe, of a very singular nature. Geognosy has been linked more closely than ever with the physics of the earth, so that, from henceforward, these two sciences, one only excepted, the noblest that can engage the rational faculties of man, and on which, if I mistake not, the most powerful intellects will hereafter expand themselves, must proceed hand in hand together. In the preceding pages no complete theory of springs has been developed, finished in due proportion in all its parts, for this our data are as yet insufficient. I have endeavoured, however feebly, to sketch out the principal points worthy of attention and inquiry, conceiving that a consciousness of our ignorance is the first step to be made in advancing to true knowledge.

## CHAPTER IV.

## MEDICINAL VIRTUES OF MINERAL AND THERMAL SPRINGS.

MANY volumes have been written upon the medicinal virtues of mineral waters. Some of these are the productions of physicians, possessing extensive opportunities of experience, and animated with a zeal for the honour of their profession, as well as the health of the invalids committed to their charge. Another and a very numerous class of these works have unfortunately been made subservient to the purposes of sordid interest, or impudent quackery. But in hardly any do we find an attempt at generalization. They are for the most part confined to empirical details of the effects of each spring upon the individual organs of the body,—the materials for an edifice rather than the superstructure itself. Medical men have either on the one hand clung to the old notion of the specific influence of natural waters; or, abandoning this, have, by a sort of antithesis, run into the opposite extreme of magnetical and electrical hypothesis. Very few seem to have thought of applying to them those general principles of therapeutical agency resorted to in explaining the effects of other remedies in disease.

Experience, it is true, can alone be relied on with safety in judging of the sanative influence of any spring in a particular affection. Still, however, while the human body remains the same, and the symptoms of diseases present certain definite and fixed characters which can always be extracted from the modifications induced by idiosyncrasy, exciting cause, &c.; certain determinate effects will in all cases be produced on these symptoms by the use of such springs,



Conformably to these ideas, in the subsequent observations I shall not enter minutely into the various diseases in which mineral waters have been at times employed; for the nosology does not contain one perhaps which they have not been supposed at some time or other to benefit. Nor shall I examine in detail the effects of each spring which has been famous for its healing powers, for upon this a goodly volume might be written, without by any means exhausting the subject. I shall endeavour with all possible diffidence to reduce thermological medicine to some general principles, which may perhaps aid us in an investigation into their correct medical application.

Murray, by his chemical researches, has shewn in a very striking manner, though some will say rather theoretically, the great, and in many cases dangerous, errors into which the physician might fall, who, *a priori*, judged entirely of the medicinal effects of a mineral spring from the experimental results of chemical analysis. And we cannot forget, that the effects of a spring are often decidedly the reverse of what we should expect from its known chemical composition. Sometimes even, as has been more than once hinted in the foregoing part of this essay, common drinking springs contain more mineral matters than medicinal waters of great reputation; nay, in many of very great celebrity, chemistry has been able to detect so few active ingredients, that several have attributed their virtues solely to the great purity of their water. If this be the case with cold springs, it will certainly hold with increased force in regard to those possessing an elevated temperature. Warmth not only enables them to hold in solution a much larger quantity of active ingredients, but will give to very minute quantities a vastly increased activity; and finally renders soluble those deemed least so, as silica itself. The physician, anxious to discover the truth, will resort to the fountain head, and there, from a continued series of experiments and observations, deduce conclusions founded upon irrefragable data. Impartial experience must certainly decide upon the merits of a spring, in those cases

when its effects differ from, or are disproportionate to, the results that we should expect from its chemical analysis.

But, although I assume experience to be our principal guide in judging of the real effects of any spring, more especially of hot ones; let it not be supposed that I undervalue chemical analysis, or am of the number of those who regard them as specifics prepared by the hand of Nature for the cure of the more obstinate maladies with which human nature is afflicted. This would be to render the whole a system of mystical empiricism, and to place an insurmountable barrier to the acquirement of any true theory of their action, totally incompatible with the present state of medical science. An accurate view of the proportion of acids and bases contained in a mineral water, enables a physician to form a *general* estimate of its medicinal virtues from its synthetical resemblance to one, with the *exact* effects of which he is already acquainted. And it is chemistry which enables him to class his observations on which to found a rational theory of their mode of operation. The details of the chemistry of mineral waters would furnish many instances of the above position. I shall only cite in illustration one or two of the most recent. The saline waters of Sales in Piedmont were long noted for their efficacy in cases of scrofula and bronchocele, and so far empirically their effects were known and valued; but it was not till Angelina in 1820 discovered the presence of iodine, that a satisfactory solution was afforded of the phenomenon. And almost the only brine springs which have been ever celebrated as medicinal agents, are those of Ashby de la Zouch in England, and Kreuznach in the Palatinate, both of which have been recently discovered by Daubeny and Liebig, to contain an unusually large proportion of the very active principle—the hydrobromate of magnesia, long after their medical reputation was completely established.

It must also be remembered, that in many, perhaps in all, springs, there are certain volatile ingredients which are incapable of being detected by the most delicate ana-

lysis. We know what a powerful influence in modifying the other solid matters, is possessed by the small proportion of carbonic acid and sulphuretted hydrogen gases, which we are able to conduct into our pneumatic trough. If such be the virtues of ingredients which we do know, it is not unlikely that similar, or even more powerful, will result from others of whose existence we are entirely ignorant<sup>1</sup>. The mere emergence of mineral waters from their subterranean laboratories, and the contact of air and light, together with the sudden diminution of the pressure under which they became charged with their different gaseous and solid matters, will of themselves, produce considerable changes in their medicinal efficacy; and is a strong argument for their being employed immediately on their issuing from the bowels of the earth. Thus far we may go with safety. But when we are told of odorous emanations, only cognizable within a few lines of the water, and which convey away in a gaseous form carbonate of iron and other active tonic principles, we are compelled to hesitate and to inquire into the probable fallacy of such nice distinctions<sup>2</sup>.

In judging of the medicinal effects of a mineral water, it is important to discriminate what portion of these are to be ascribed to the mere water itself, what to its elevated temperature in the case of thermal waters, and what to its foreign ingredients.

<sup>1</sup> *Hufeland* in his *Praktische Übersicht der vorzüglichsten Heilquellen Deutschlands*, 2d edition, 1820, p. 12, has the following passage so much to the point, that I cannot forbear from presenting it to the reader entire:

“Doubtless the use of mineral waters immediately from the spring, that is, from the living hand of Nature herself, is the only true method by which we obtain their products in all their power and purity. The slightest separation from the common mass, from their usual temperature, the mere removal from their subterranean laboratories to the contact of light and atmospheric air, must produce a very considerable decomposition of their more delicate matters. So that we should, properly speaking, drink them with our lips immediately applied to the spring itself, and when that is not possible, carry the cup with the utmost speed to the mouth; for it is certain that every moment’s delay is accompanied with a loss of medical powers.”

<sup>2</sup> *Kastner’s Archiv*. xiii. 430; 1828.



The simple circumstance of dilution will certainly facilitate the operation of matters which might otherwise pass little changed through the alimentary canal; and, from the extremely minute state of division in which the active particles are presented to the sentient mouths of the capillary absorbents, it is more than probable that they are directly absorbed into the circulating mass. Indeed, in no other way can we explain the powerful effects which result from the use of many chalybeate springs. The strongest of these does not contain more than five grains of the carbonate of iron in a gallon of water. The real quantity of this tonic received at a single dose into the stomach, or contained in a pint of water, must therefore be extremely small; and nevertheless it will exert a more salutary influence upon the system, than twenty times the dose of the artificial carbonate in our ordinary prescriptions.

Dr Saunders, in his excellent work, enters into a very elaborate and refined train of arguments, in support of the idea that dilution acts by presenting a greater surface of contact for the active ingredients upon the nervous papillæ of the stomach<sup>1</sup>. This may co-operate with absorption in promoting the effects of minute particles of matter; but must necessarily be very transient, and entirely subordinate to the lasting change of constitution, which could only result from the direct application of the active agent to the moving solids. Certainly in those springs which contain a large dose of carbonic acid, nervous stimulation accounts very well for their primary exhilarating powers on the cerebral system, but on this supposition their subsequent effects are entirely inexplicable.

Along with minute division of parts, elevated temperature exalts, in a very high degree, the active powers of mineral springs. It renders them so extremely stimulant, that none can be taken for a great length of time, or in any considerable quantity, without producing disagreeable, and even dangerous, effects, at least in their

<sup>1</sup> Treatise on Mineral Waters, p. 377-386.

most concentrated form, until, by previous dilution or cooling, they are in part deprived of their warmth, and a considerable proportion of their volatile ingredients.

*Dilution* and *Warmth* are very powerful auxiliaries in promoting the medicinal powers of mineral waters,—but they are still mere auxiliaries. To the foreign substances which they contain, must be ascribed their real sanative virtues. The extremely minute quantity of these substances cannot be surely adduced as an argument for refusing to them such powers, when we have such an accumulated mass of experience in their favour. When used externally in the form of bath, it is very probable that in many instances their effects do differ little from those which would be produced by pure water raised to the same degree of heat, in some internal disorders at least. But when used internally, the comprehending in our estimate the three conditions above referred to will become a far more difficult task, as well from the varying susceptibilities of different temperaments, as from the presence of very minute, and perhaps even inappreciable ingredients, which may play a very important part in modifying their qualities, if, indeed, it may not preclude our ever arriving at a complete theory of their *modus operandi*.

Lastly, we may notice their moral influence on the mind. Many, as formerly observed at the opening of this Essay, doubting any real curative effect in the waters themselves, have ascribed entirely to this cause the beneficial effects accompanying their use. It is not improbable that, in many comparatively innocuous diseases, especially in those dyspeptic cases where the chief symptoms are a depression of the natural and healthy elasticity of the animal spirits, unaccompanied with any organic visceral disease, a change of scene and habits may alone effect a material improvement in the state of the patient; aided not a little by the power of the imagination ascribing all to his morning libations. But to extend this principle to every case, and to lay it down as a general proposition, that this is the secret of all their boasted cures; or that imagination will remove organic

hepatic disease, scrophulous and mesenteric disorders (for the argument amounts to this), is, I conceive, to anticipate experience, from the eager wish to support a preconceived favourite hypothesis. I am well aware that this opinion bears the sanction of many names illustrious in the annals of medicine. But that it was supported even by a Cullen, is no argument for our shutting our eyes to the lessons of experience, or to the dictates of a more improved pathology, which this very candid physician, had he now lived, would have perhaps been himself the very first to admit. In some cases, too, very beneficial effects may be ascribed to the exhilarating influence of mountain air and beauty of scenery. It is yet notorious, that many of the most celebrated mineral springs are in situations directly the reverse of this, not remarkable for purity of air, and certainly still less so for beauty of scenery.

We agree with Alibert<sup>1</sup> in regarding all thermal waters, and most mineral springs generally, to be physiologically and therapeutically *stimulant*; and that the degree of excitation is proportionate to their temperature. This may be stated to be the fundamental principle of thermological medicine; and is therefore of the utmost importance to be kept in view in determining the particular class of diseases, or the particular stage of any given disease, which they are likely to benefit. This stimulant power may be directed to very different organs. They may sometimes act by exciting the capillary circulation, the secretion of urine, the alvine excretions, the digestive functions, the locomotive organs, or, finally, the nervous system generally. In the early or acute period of a disease, they will seldom be beneficial, in most cases highly injurious; especially in that great class comprehended under the general title of *Pyrexiaë*. But when it has assumed the chronic or indolent character, signal benefit will frequently result from their judicious application.

In the early periods of medicine, and, indeed, till very

<sup>1</sup> *Precis Historique*, p. 11.



lately, there was not a single disease for the cure of which a patient was not recommended to have recourse to mineral waters ; for the most part after the failure of all the ordinary modes of cure, and perhaps when his constitution had been debilitated by the operation of innumerable active remedies, administered without any definite object, in the hope of their making some considerable change in the constitution, and by this shock, of dislodging the cause of the disease <sup>1</sup>. This list has been much restricted by subsequent experience, and a more accurate knowledge of the *ratio medendi*, and of the proper province of art in promoting the expulsion of the morbid causes. In all, their stimulant effects must be cautiously guarded against. And in those cases where any fever is present, whether of the phlogistic or hectic type, or where there is much general plethora, it will be prudent to defer their use till these symptoms are subdued by the appropriate constitutional remedies.

It is, however, a very erronecus opinion to suppose that the healing powers of mineral waters are only to be resorted to in extreme cases,—as a sort of *dernier ressort* after the failure of all our artificial modes of cure. I conceive that much of the ridicule which has been attempted to be thrown on the curative powers of natural springs, may be traced to this cause,—to their use being only recommended in cases where the constitution is nearly exhausted, and the *vis vitæ* well nigh extinguished by long protracted disease, as well as by the number and variety of the modes of treatment to which the unfortunate patients have been previously subjected. From the astonishing effects which they have produced in not a few of even these extreme cases, we are entitled to conclude, that their early employment would be one of the speediest means of effecting a satisfactory cure in many disorders, especially in some of those cachectic and dyspeptic derangements of the system, which are at present, unhappily for the human species, too truly the *opprobrium medicinæ*.

<sup>1</sup> *Heberden's Commentaries on the History and Cure of Diseases*, 1806, p. 7.

I shall now proceed to make a few observations upon the general effects of the different classes of mineral waters, and the principal diseases in which they are serviceable, upon the forms in which they are employed as medicinal agents, and shall conclude with a few practical hints to be attended to during their use.

## SECTION I.

### GENERAL EFFECTS OF THE DIFFERENT CLASSES OF MINERAL SPRINGS.

I NEED not repeat the remarks which have been made at p. 81 regarding the impossibility of subjecting mineral waters to a strictly technical arrangement, whether upon chemical or medicinal principles, or upon a combination of both, from the want of isolation of what have been considered as their characteristic ingredients, and the grouping together, in many instances in nearly equal proportions, of substances possessing active and opposite qualities. It will, therefore, be the object of this section briefly to state the leading effects which the most important ingredients confer upon different waters, and the modifications induced in these by the other coexistent substances. In this point of view, it is of very little importance what arrangement is followed.

I. *Chalybeate Waters*: *Oxide of iron* characteristic. This mineral is found in almost all waters, in greater or less quantity; but it only forms the type of a particular medicinal class, where its effects are the most conspicuous. The principal agents in modifying the dominant effects of the iron, are carbonic acid, which most chalybeates contain in greater or less quantity; other neutral salts, either alkaline or earthy; and the sulphates of iron or alumina, alone or together.

The principal effects of these waters are *tonic* and *astringent*, and their permanency principally depends upon

the proportion of the carbonic acid. To this gas must also be ascribed the facility with which they are borne in very weak states of the digestive organs, so different from the artificial preparations of iron. Their principal action is on the circulating and muscular systems, accelerating the motions of the former, and giving strength and tonicity to the latter. They are also very useful in morbidly excited states of the nervous system, arising from debility, by whatever cause induced. The aluminous chalybeates are generally so extremely astringent, that they cannot be drunk without previous dilution, and even then are very apt, in delicate constitutions, to excite oppression at the stomach and cardialgia. When associated with a certain proportion of the purging alkaline or earthy salts, they may be employed in a more plethoric state of the system than that in which their use is generally advisable.

Generally speaking, they are contra-indicated in all plethoric states of the system, or dispositions to active hæmorrhagies or inflammations, as well as in all febrile states, whether of the inflammatory or the hectic type. Neither are they advisable in disordered states of the *primæ viæ*, till these are rectified by the appropriate purgative remedies. We must be particularly on our guard against their incautious use in a tubercular pulmonary diathesis, where they may excite cough, and an active state of inflammation. And in general, perhaps, it is better always to premise a regular course of a chalybeate water by the preparatory use of some resolvent medicines, whether artificial, natural waters with a considerable proportion of neutral salts, or chalybeates where the iron is associated with these salts; only perhaps in cachectic and leucophlegmatic states of the system is it advisable to resort directly to their regular use. In visceral obstructions, too, whether of the liver or spleen, their use is by no means advisable. Nor must it ever be forgotten what a powerful effect the elevated temperature of thermal water possesses in exalting the stimulant effects of the iron.

When they agree with the constitution, they will not



cause any oppression at the stomach, but an increase of appetite; they will produce no permanent determination of blood to the head; the regular daily evacuations by stool will become of a dark colour; and there will be the frequent discharge of flatus.

II. *Sulphureous Waters*: *Sulphuretted Hydrogen* characteristic. The general effects of these waters are *stimulant*; and in this respect, they are decidedly the reverse of the chalybeates, their effects being much more transient. Their action is chiefly exerted upon the liver and the system of the vena portæ; also upon the mucous coats, and the cutaneous tissues. The hot sulphureous waters are extremely penetrating and stimulant. These dominant effects are principally modified by carbonic acid, which, in the cold sulphureous waters, accompanies the sulphuretted hydrogen in greater or less proportion, and often even exceeds it in absolute quantity; but from the very penetrating and active properties of the latter gas, it is a subordinate medicinal agent;—and different alkaline and earthy sulphates, which contribute to diminish the stimulant and heating qualities of these waters, by their resolvent powers on the alimentary canal. When iron is present in this class, it contributes to neutralise the effects of the sulphur, and also to render them more permanent.

This class of waters, whether cold or thermal, are more frequently used externally in the form of bath, than internally; for sulphuretted hydrogen becomes very penetrating when assisted by heat, although water at 80° or 90° F. can only be made artificially to absorb an equal volume of the gas.

Sulphureous waters are extremely serviceable in gout and rheumatism, when these have degenerated into the chronic form, and in the stiffness and rigidities of the joints and ligaments, which continue long after the cessation of inflammatory action; in sprains and bruises, as well recent as upon the numerous train of troublesome symptoms which they leave behind them; in chlorosis and those multifarious derangements of the uterine sys-

tem with which the female constitution so extensively sympathises, this class of waters has acquired great and merited reputation ; and also in syphilitic disorders which have passed into the secondary stage and become rooted in the constitution. But it is on the tegumentary system that their most special effects are apparent, to which sulphur, naturally a specific for many of its diseases, is thus presented in its most penetrating and active form, aided by the detergent power of the water itself. Accordingly, in Lepra, Herpes, Scabies, Elephantiasis, &c. this has long been a remedy of the very first importance where it can be procured ; not merely as preparatory to the use of other substances, by restoring pliancy and perspirability to the skin, and putting a stop to that continual desquamation of the cuticle, which is frequently one of the most obstinate symptoms with which the physician has to contend ; but is itself also the sole agent under which all the formidable symptoms successively disappear. It would be a curious subject for experiment, and might perhaps lead to some useful practical results, to try the effects of some of those waters which contain a large dose of sulphuretted hydrogen (a most powerful sedative), in some of the more violent and intractable of spasmodic diseases, such as Tetanus, Hysteria, and Hydrophobia.

In this, still more than in the preceding class, caution is necessary in their use, particularly in an irritable state of the vascular system ; in general plethora, or active hæmorrhagies, especially from the lungs.

III. *Acidulous Waters*: *Carbonic acid gas* characteristic. This gas is a still more universally diffused ingredient than iron, being found in by far the greater number of mineral waters. But it is only when its quantity is such as to exceed the effects of the co-existent solid or gaseous matters, that it can be considered as characteristic of the water ; at the same time, that these exert an important influence in modifying its properties. The mere absolute quantity of carbonic acid is therefore by no means a standard of an acidulous spring ; for this may

be very small, and yet a water may be referable to this class, if accompanied with a still smaller quantity of saline substances; and often a very small proportion of very penetrating ingredients, such as oxide of iron or sulphuretted hydrogen, especially in thermal springs, is sufficient to neutralize a large proportional quantity of this gas. Generally speaking, however, we may assume, that a true acidulous spring seldom contains less than 40 cubic inches of gas in 100 of water; and the quantity of oxide of iron is not more than half a grain in 10,000 of water. There are even examples of springs which are most largely impregnated with the gas, such as those of Pyrmont and Spa, not belonging medicinally to this class, in consequence of the predominant effects of the iron.

It is of the utmost importance, in judging of the utility of an acidulous water, to take into account the degree of fixity of the gas. Some lose it with the utmost facility upon exposure to the air, or a very slight elevation of temperature, even without the aid of agitation, which always has the effect of disengaging a considerable proportion from those which are impregnated beyond the point of saturation under the ordinary atmospheric pressure. The co-existence of different carbonated alkalis and earths has doubtless much influence in adding to the fixity of the carbonic acid; but the diversity in its cohesion to the water is in many instances to be ascribed to causes of which we are yet ignorant, particularly in the case of thermal waters.

Of all mineral waters, the acidulous are most remarkable for the *volatility* and transient nature of their effects. These are chiefly exerted upon the nervous system and the digestive organs. In torpid states of the former they act as very salutary stimulants to the nervous papillæ of the stomach, and thence react upon the encephaloid organs. In dyspepsia they are often exceedingly advantageous, both when pure and still more when associated with a certain quantity of the oxide of iron, or with a proportion of the laxative alkaline salts, such as the carbonate or the muriate of soda. In leuco-



phlegmatic dropsies, their agency is often very salutary in exciting the dormant absorbents and promoting the urinary secretion; and in certain calculous diatheses much benefit may result from their judicious use, particularly in the lithic acid variety, when associated with the carbonate of soda, or in the form of acidulo-alkaline springs. From the mildness of their action, they are often preferable to any other class of mineral waters in very debilitated states of the system, whether from nervous or organic disorders, which have degenerated into the chronic state.

When slightly thermal, they are often more easily borne by the stomach, particularly in irritable states of the system, or a disposition to pulmonary congestion. They are almost always used internally, seldom in the form of bath; and always at the spring, for by transport a large proportion, sometimes the whole, of the carbonic acid is expelled, and the iron, which contributes so much to their salutary effects, is precipitated<sup>1</sup>. The stimulant action of the carbonic acid is often mollified, by mixing the natural water, immediately before its being drunk, with milk or whey.

One of the primary phenomena observable on commencing the use of acidulous waters is a sensation of fulness in the head, indicative of a determination of blood to that organ. They must, therefore, be very

<sup>1</sup> Different methods have been proposed to obviate the precipitation of the oxide of iron in acidulous and chalybeate waters, during their transport. I shall only mention two of the most recent.

The first was proposed by Professor Steinmann of Prague (*Hesperus* for August 1821). It is founded upon the idea that the hydrated oxide of iron, which falls to the bottom of the most accurately corked bottles, might be separated by the tannin and gallic acid contained in the cork, as this is often coloured black at its point of contact with the water. He therefore advised the corks to be previously boiled, in order to extract these two principles, and found that, in bottles closed with boiled corks, the oxide of iron was not separated, after having stood for a considerable time, but amounted, by analysis of the water, to the original quantity of water contained in the spring.

The other method, originally suggested by Klaproth, and lately revived by Link (*Hufeland's Journal*, lxiv. st. 5, p. 3), consists in merely driving an iron nail through the cork. It has been even alleged that this increases the amount of iron held in solution by the water; (*Kastner's Archiv*. vii. 192, and xiv. 58.)

cautiously employed in irritable states of the vascular system, in plethora, congestive diatheses, hemorrhagies, and inflammations. On the contrary, when it is an object to produce a temporary local plethora, as in chlorosis and amenorrhœa, this quality is rather an indication for their use. When associated with a more than ordinary proportion of refrigerant salts, their laxative effects will more than counteract this tendency to congestion.

IV. *Purging Waters: Sulphates of soda or magnesia* characteristic. Medicinally, as well as chemically, the most prominent difference between this and the foregoing classes consists in their much larger proportion of fixed saline matters. Carbonic acid is always an insignificant ingredient, although doubtless even this small quantity contributes to render them more easily borne in weak states of the digestive organs. Exposure to the contact of air, and to the agitation of land carriage, has much less influence in altering the characteristic features of their medicinal qualities. On account of their large impregnation with solid matters, they are sometimes liable to cause oppression of the stomach, neither can their use be continued for any great length of time.

The primary effects of the class are a relaxation of the bowels, and an increased flow of urine. They are, therefore, in the truest sense of the word refrigerant and *antiphlogistic*. But these effects are almost never accompanied with those debilitating consequences which would infallibly follow the continuance of an equal dose of artificial salts for a much shorter time in our ordinary prescriptions, or even of what are called factitious mineral waters. This is certainly a very singular fact, for which it is difficult to give a satisfactory explanation, and one which shews in a more striking manner than any which could be adduced how far we are yet, notwithstanding the advanced state of our chemical knowledge, from understanding the real secret of the combinations in natural mineral waters. Can this difference be owing to minute quantities of iron? This metal is an element very universally diffused in nature, and is found

to pervade the greater number of thermal waters ; and, however minute its proportion, it must have considerable effect in modifying their influence on the human body when possessed of cathartic powers. This, however, is a pure conjecture, for it is difficult to suppose that a proportion of iron quite inappreciable by the most delicate reagents, can be capable of modifying in so considerable a degree the normal effects of this class of remedies.

In plethoric constitutions, therefore, or persons disposed to active congestions or inflammations, this class of waters may be very useful. Also in hæmorrhoids, in cerebral symptoms, such as vertigo, tinnitus aurium, *muscæ volitantes*, &c., in habitual constipation, giving rise to constitutional derangement.

The modifications in the normal properties of this class most important to be attended to, are those depending upon the presence of a more than usual quantity of carbonic acid, and the circumstance of thermality, not unfrequent where sulphate of soda is the principal ingredient. Both of these concomitants, more especially the latter, will render more caution requisite in their use as depleting remedies, as they will materially increase their stimulant powers. The alkaline purging waters, when not so largely impregnated with solid matters, will stimulate the urinary organs, and become useful in calculous diatheses.

When the effects of the natural waters are not sufficiently strong, some authors have recommended<sup>1</sup> the augmenting their power by the addition of a small quantity of the deposit obtained by the evaporation of certain mineral waters, and which are known under the names of Seidlitz, Salschütz, or Epsom Salts (not artificially prepared salts), to each dose of the ordinary spring. The propriety of this practice is, however, very doubtful. When a water is not sufficiently strong to produce the desired effects, it is more advisable either to increase its dose, or, if this is inconvenient, to resort to the use of a

<sup>1</sup> *Osann*, *Darstellung*, H. i. p. 256.



water which naturally contains a sufficient saline impregnation. Their use has been also recommended in the torpid state of the bowels, so troublesome during pregnancy. Here the weaker varieties of the class may be of much service, from the mildness and regularity of their effects compared with any of our artificial remedies.

V. *Saline and Brine Waters: Muriate of soda* characteristic. Of all the classes of mineral waters this is the most remarkable for its large proportion of saline matters. In regard to their general effects, they might be ranged with the preceding class, and would hardly have merited a distinct consideration, were it not for the peculiar effects which many of them produce in glandular affections usually considered of the scrophulous character. They seem in such cases to act as stimulants to the absorbent system, as well as to cause a permanent change in the constitution. This peculiar influence of these springs has long been known, but was considered incapable of satisfactory explanation till the discovery of iodine and bromine among the ingredients of mineral waters; although doubtless the other co-existent muriates generally found in these waters, such as the muriate of magnesia, and more especially the muriate of lime, hold an important share in these virtues. With regard to iodine, its quantity is so very small that, as Professor Daubeny suggests, it is doubtful if we can attribute to it much medicinal efficacy, not amounting in the strongest of the British springs which have been examined (Robbin's Well at Leamington) to more than a single grain in ten gallons of water; nor on the Continent (Salzhauzen near Frankfurt am Main) to much more than half a grain in 10,000 of water. Yet, after the elaborate and elegant experimental researches of Lugol, on the medicinal effects of this substance<sup>1</sup>, who found so dilute a proportion as half a grain in a pound of water daily of the most beneficial effects, and in the most

<sup>1</sup> Essays on the Effects of Iodine in Scrophulous Diseases, 1831.

aggravated cases seldom administered more than one grain per day in twelve ounces of vehicle, we cannot be sceptical of its agency when continued for a great length of time (an indispensable condition to its success) in the very dilute state in which it exists in natural springs. There is no doubt that the co-existence of a large quantity of muriate of soda will often be an obstacle to its administration in this form for a sufficient length of time. In some springs, however, it has been found, where no muriate of soda whatever exists, and in which the smaller quantity of solid matters generally forms a less insuperable objection to their use (Llandrindod).

Bromine is a substance which exists in much larger proportion in saline springs; but we are not sufficiently acquainted with its precise therapeutical agency to estimate the due weight to be ascribed to it in the medicinal effects of mineral waters. At all events, from its very active poisonous qualities, it must be an agent of considerable power. And one thing is certain, that Ashby-de-la-Zouch, a brine spring which has been long celebrated in scrophulous disorders, does not contain a trace of iodine, but is remarkable for its unusually large proportion of bromine.

The stimulant powers of these, as well as of all the other constituents of this class of springs, will be much exalted by the increased temperature which many of them possess. The small proportion of carbonic acid in some of the cold ones will probably render them more easily borne by the stomach, and will be useful in counteracting the disadvantageous effects of their large impregnation of solid matter. The presence of iron is also important to be attended to, as augmenting their tonic effects.

Except when viewed as remedies in scrophulous disorders, this class of waters are fully as useful when used externally as internally. In this respect they are closely allied to sea water. Their tonic powers may be very beneficial in chlorosis, chorea, and nervous disorders, when not used, as perhaps they never should be, at a very high temperature. They must, however, be per-

severingly continued in for a length of time, although no decided result should follow their first application. Such as contain the carbonate or sulphate of lime in very considerable quantity may exert a constringing power upon the superficial capillaries, distinct from that which would follow their incautious use when too hot; and may hence be beneficial as an auxiliary to the constitutional means in the tendency to profuse perspirations, which often accompany debilitated states of the body, from whatever cause induced.

VI. *Alkaline Waters: Carbonate of soda* characteristic. More difficulty occurs in assigning the correct medicinal powers of this than of any of the other classes of mineral waters. It is one of great extent, and includes a great variety of springs. Very frequently the amount of solid matters is very small; in some thermal springs not exceeding one grain in 10,000 of water. The chief agents in modifying the normal qualities of the alkali are an elevated temperature, the presence of carbonate or sulphate of lime, carbonic acid, and other neutral laxative salts; a comparatively small quantity, however, of these last substances is sufficient to neutralize altogether the alkaline qualities of the water, or to render them entirely subordinate, and to refer the spring to the purging class.

The regular action of alkaline waters is on the urinary apparatus chiefly. They stimulate the action of the bladder, and exercise a specific influence on the kidneys, changing the quality of the urine, and preventing the formation of calculi, or dissolving them when already formed, and still of inconsiderable size, or in the state of gravel. In the lithic diathesis of gout, they are very advantageous, as well as in the anomalous dyspeptic disorders so often accompanying this complaint, of which acid in the stomach is one of the principal symptoms. It is alleged by Osann, that the long continued use of alkaline waters may exert so decomposing an effect upon the animal fluids as to induce a state of the system very analogous to scorbutus. In ordinary cases of dyspepsia,



where acidity in the *primæ viæ* results from the want of tonicity of the muscular coat, they may be of much use when associated with a considerable quantity of free carbonic acid, which will be materially assisted if iron should be also present. The thermal springs of the class, when the alkaline impregnation is at all considerable, are extremely stimulant, and may be very beneficial in highly atonic states of the system, or in very rigid fibres, the *temperamentum siccum*, if not contra-indicated by other symptoms, such as hydropic states; febrile disorders, whether primary or hectic, arising from internal ulceration; congestive hæmorrhage, or inflammatory habits; and in a hereditary tendency to pulmonary tubercles, from the artificial excitation they produce in the system somewhat analogous to the mercurial erethism.

Externally they are useful in many chronic eruptions, chiefly perhaps from their detergent qualities. All these observations, however, apply to those which are tolerably impregnated with alkaline matter, for, in some, the quantity is so small that they cannot differ much from nearly pure water; and, in others, all their efficacy must be ascribed to the large proportion of free carbonic acid.

Such is the brief, and I fear but imperfect, outline which I propose giving of the general effects of the different classes of mineral waters. From one spring often containing several ingredients belonging to different classes in nearly equal proportions, it may combine the effects of two or more of the distinct classes, or may even produce a result agreeing with none of them in their operation. This is one of the greatest difficulties we have to encounter, and will ever prove a great, if not an insurmountable, obstacle to the construction of a complete theory of their action, independent altogether of empirical views. But as such combinations may be multiplied almost to infinity in the ratio of the number of active ingredients hitherto discovered, some classification is indispensably requisite; and this may be grounded with most safety upon their most prominent and characteristic constituents. From this combination

of several valuable qualities in one water, they may be used in cases of very opposite descriptions, which, among the older physicians, gained for them the appellation of a *Universal Medicine*, when their mysterious origin was a good and sufficient plea for referring to them a thousand occult qualities, characteristic of the dawn of an enlightened philosophy. If we consult even some of the most recent and approved continental works upon their medicinal effects, from the long catalogue of acute and chronic disorders which they are said to benefit, we might be inclined to suppose that they have lost in this respect but little of their ancient celebrity. There is no doubt, however, that these great natural reservoirs of healing efficacy are to be considered in the light of equivalents, not substitutes, for our artificial remedies, and as such they are agents of real value.

It would lead us into a field by far too extensive, and one which has been in a great measure previously traversed, to enter into a detail of the effects of the vast variety of mineral springs on each individual function of the system, and on the derangements of its normal state arising from disease. Nor can we enter into the nice distinctions by which one spring differs from another in its effects under apparently very similar circumstances of chemical composition, temperature, and constitution of the patient. And yet it is perhaps only after such a detailed series of observations, and a summation of the assemblage of facts, that a theory of their operation can be framed which shall be complete in all its parts.

## SECTION II.

### FORMS IN WHICH MEDICINAL SPRINGS ARE EMPLOYED.

THIS is a point of the very first importance to be attended to in the use of mineral springs as medicinal agents. It is determined by several different circumstances, by the nature of the disease and the organs

which we principally wish to affect, by the quality and quantity of the ingredients in the mineral spring, and by its temperature. When drunk at the source, or used as a bath, without being artificially heated or cooled, or having been much exposed to the contact of the external air, the spring must certainly manifest its most genuine effects; for these causes have always the effect of disengaging a greater or less quantity of gaseous matter, and of precipitating substances but feebly united to the water.

When it is wished to impregnate the constitution fully with a mineral spring, to bring it completely under the state of artificial excitation which they usually produce, it is necessary to continue their use for about four or five weeks, drinking daily not more than from four to twelve tumblers; or, if used externally, from twenty-four to thirty baths in the same space of time. Much, however, depends upon the rapidity with which the system is charged with this quantity. In by far the greater number of cases, it is advisable to commence with small doses, which may be gradually increased as we find them to agree with the stomach of the patient, and the symptoms of the disease. To begin at once with large doses, especially of the more stimulant thermal waters, is only allowable in very atonic states of the body, or in diseases where a powerful stimulus is necessary. Such a method with weak, nervous habits, or irritable states of the digestive organs, would be attended with the worst consequences; it might lead to hæmorrhages and local congestions, to dropsy, or, in very plethoric states of the system, to apoplexy, and other formidable complaints arising from over excitation of the nervous and vascular systems. Much will depend not only upon the quality of the water, and the disorder of the patient, but also on the heat of the season, and the locality of the watering-place, or the conflux of visitors and other variable causes. In the same way, the use of the water should not be left off at once, but should be diminished as gradually as it was increased.

Not unfrequently, mineral waters are not the sole agents depended on for the cure of a disease, but are



merely employed as subsidiary to the use of other remedies; such as acidulous waters in calculous complaints, and purging waters in plethoric states.

Before commencing the regular course of a mineral water, it is not an uncommon practice to premise the use of a few simple preparatory remedies. This is attended with the best effects, and is indeed necessary, in plethoric or congestive states, or in deeply-rooted chronic complaints, before resorting to the very stimulant springs. Artificial remedies may be used for this purpose, or, what is better, some natural waters of a laxative and refrigerant quality.

Should much nervous erethism remain after the cessation of a course of mineral waters, a few doses of some of the milder acidulous springs may be beneficial, or a journey among mountain scenery, and a course of milk diet at some of the mountain villages: or if considerable debility should persist, a short course of some chalybeate, accompanied with the use of cold or tepid sea-water baths. These subsequent precautions are particularly advisable in gout, dropsy, calculus, or other complaints liable to experience a relapse upon too sudden a change of habits.

1. *Internal Use.*—Generally speaking, the larger the proportion of gaseous matters, and the smaller that of the fixed, the more easily is a spring borne by the stomach. Even a large quantity of solid matters, very apt to disorder weak states of the digestive organs, may be borne with the aid of an increase of temperature on a more than ordinary quantity of carbonic acid. The primary phenomena observed on commencing the internal use of thermal waters, are a sensation of fulness in the head, a relaxation of the bowels, or an increased flow of urine. The first of these symptoms generally subsides after their use has been continued for a period of two or three days. If these effects should be too violent, or should persist for too great a length of time, it has been advised to diminish the stimulant effect of the water by allowing it to cool and to promote the escape of volatile

matter by free exposure to the air, or by mixing it with warm milk; but as all these methods produce changes in the constitution of the water, which neither the physician nor the chemist can exactly appreciate, it is probably better to resort at once, if possible, to the use of another water whose natural qualities present the wished-for conditions.

The springs set apart for drinking should be contained in stone reservoirs, and excluded as much as possible from agitation and free exposure to the air. And the same precautions should be observed by the invalids in drinking them. If artificial heat is from circumstances necessary, it should never be applied directly by a fire, but by plunging the cups into a vessel of warm water. Close to every spring there ought to be spacious covered promenades, in order that the necessary exercise may be taken between the doses of water, without being exposed to the inclemencies of the weather.

Unavoidable circumstances may, however, render it impossible for an invalid to drink the waters at their source. It then becomes an important consideration how they can be transported with least detriment to their medicinal efficacy. Thermal waters, and those highly charged with gaseous matter, are those which are most deteriorated by carriage. The vessels in which the water is contained should of course be hermetically air-tight, and the precautions formerly referred to should be adopted with respect to the cork. They should, if possible, be filled and corked up under water, in order allow as little as possible of the escape of gaseous bubbles. Season, weather, and the hour of the day, are all circumstances which ought not to be neglected, especially in those springs where annually many tons are transported, such as at Selters, Pyrmont, &c., becoming an important article of trade. The spring season before the commencement of the annual influx of visitors, the morning and dry weather are, for obvious reasons, the periods at which the spring, from being least disturbed, will present all its qualities in their most normal and concentrated states.

2. *Water-bath*.—It is very probable that, when used in this form, their effects are more modified by temperature than by the foreign ingredients, as least those of a fixed nature. Much is also ascribable to the duration of their action. Those of the thermal class produce a powerful determination to the surface and to the head, as evinced by the turgescence of all the superficial capillaries, the flushed countenance, the vertigo, and the general relaxation or exhaustion arising from the determination of the blood, from the more internal and noble organs. Of all the organs, the skin is that most affected by the use of mineral waters in this form, its irritability is for a time increased, and its mode of action permanently altered, especially by the hot sulphurous waters. They sometimes even produce a peculiar eruption, to which the name of *Psudracia thermalis* has been given, which is by no means critical, but runs through its regular stages.

Dr Saunders observes, in his excellent essay (p. 380), that “the powerful and extensive stimulus of heated water is used to very great advantage in paralytic affections of particular parts, whether the consequence of general derangement in the circulation, and the alarming reliefs of apoplexy, or arising from local injury on the spine or origin of the nerves.” Notwithstanding the high authority from which this opinion emanated, its practical application will, in many, probably in most cases, be extremely dangerous to the patient. The “powerful stimulus of heated waters” could only be beneficial or proper in those comparatively rare cases, when paralysis is owing to a mere local derangement in the nerves of that particular part. Every physician knows that the cause of the paralysis alluded to in the above quotation must be sought for in a more central and vital organ, in the cerebro-spinal axis; and that they are, in almost all cases, except those from extravasation of blood, as far as we can judge from the necroscopic appearances, the effects of inflammatory action or its sequelæ on these organs. On the other hand, I do not doubt that, in the partial or even complete loss of motion occurring in dif-



ferent joints, the residue of a protracted attack of rheumatism, the external use of warm springs is often productive of the most salutary effects, especially in the forms of pumping, douche or vapour-bath, to be afterwards considered, and when it is conjoined with sedulous friction of the affected limbs.

Those baths are, doubtless, the most efficacious which are naturally of such a temperature, that they can be employed without artificial cooling or heating. For which reason, until comparatively these few years, it was the practice to receive the water into common baths, where a certain number of patients bathed at once. But even although by the separation of the sexes, and other means, many of the objections to these public baths, in a moral point of view, have been removed, they are still liable to many disadvantages which more than counterbalance the greater freshness of the water by its continual influx and egress from the bath. Even supposing that the mineral water should possess a neutralizing effect upon the contagious nature of many cutaneous and other disorders, it must be confessed that the aspect of many miserable, often disgusting, patients is not a circumstance likely to promote the beneficial action of the bath from the shock which it must give to the delicacy of feeling so natural to every well-ordered mind.

Every bathing-establishment should therefore possess a series of private baths, with the necessary apparatus, attendance, &c., for furnishing them with thermal water at the natural temperature. If this should be too high, it can easily be provided for by an arrangement of cold and hot water stop-cocks. And it would be much preferable if, for the purpose of cooling, not river or common spring water were used but previously cooled thermal water. The baths should be each five or six feet long, four or five feet broad, and three or feet deep, and should be constructed of stone, and lined with well-polished flags, or, what is better, with earthenware<sup>1</sup>.

<sup>1</sup> It is to be regretted that so few of these establishments are provided with good thermometers. Some of the continental watering-places have a very convenient thermometer, described by *Hufeland*

3. *Affusion* or *Douche*.—By this is to be understood the forcible impulsion of the mineral water on different parts of the body. In this form of using medicinal springs, the conditions of most influence in modifying their effects are the magnitude of the stream, its force, the temperature of the water, and its mineral qualities. The common shower and plunge baths might be considered as varieties of this form, the water acting in these chiefly by its mechanical impulsion. In professed treatises on the mode of employing mineral waters, we find enumerated many kinds of affusion, the *douche descendante*, *douche laterale*, and *douche ascendante*; but these are mere modifications of the direction in which the water is applied, adapted to local circumstances.

Affusion should rarely be employed oftener than once a-day, frequently only every other day. At first, it should not be continued longer than a quarter of an hour at a time, which may be increased to half an hour in very torpid habits. Its efficacy is frequently increased by friction with the hand, either naked, or armed with a flannel glove, or even by different rubefacients. And often this is a very advantageous practice, merely as a subsidiary to promote the action of this last class of remedies. The *douche* acts as a local stimulus, often of a very powerful description, as manifested by the redness, pricking sensation, and often copious perspiration which follows its use. The diameter of the stream of water must vary with the extent of part affected, but usually is from 3 to 12 lines, and is most manageable when impelled by a machine analogous to the forcing-pump, all the parts of which should be of some hard wood (oak is the best), with the exception of the valves, cocks, &c. which must be of metal, leather, &c. in order that it may exert as little decomposing effect on the water as possible. The capacity of the re-

(Ubersicht der Heilquellen, p. 182). It consists of a common thermometric tube, fixed vertically in a disk of cork, which floats on the surface of the water with the naked bulb freely immersed in the fluid. This floats on the surface of the bath, so that the bather can regulate with the utmost precision the temperature of his bath, as well as maintain it of a uniform warmth by means of his hot and cold water-cocks.

servoir ought to be about three or four gallons, so that the stream of water may be kept up uninterruptedly for the necessary time. During the application of the douche, the rest of the body of the patient may either be simply enveloped in flannel, or immersed in the warm-bath. Some watering-places possess a peculiar kind of cover, provided with different orifices, so that the whole body is excluded from the contact of the water, except the small opening to which the douche is applied.

In its strictest sense, the affusion of mineral water is entirely a local remedy, applied to different parts of the body. It is therefore chiefly indicated in indurated or indolent swellings; in partial anchyloses or contractions remaining from dislocations; in stiffness and rigidity of the joints resulting from rheumatism or gout; as a tonic remedy in the debility of particular muscles, arising from sprains or over-exertion. In some chronic and circumscribed cutaneous eruptions, the affusion of sulphureous waters in this form may supersede the use of the general bath. And the affusion of some of the stronger chalybeate waters has been found very beneficial in chronic and indolent ulcers, or those attended with too profuse a discharge. The direct application of mineral waters has been recommended in disorders of the mucous surfaces, of the urethra, vagina and rectum, but we are as yet unable to appreciate what effects are in such cases to be ascribed to the injection of simple water, and what to its mineral matters.

4. *Vapour Bath*.—Under this I only include the thermal vapours which rise *spontaneously* from warm springs. In a medicinal point of view, they may be considered as composed of aqueous vapour, sulphuretted hydrogen, and carbonic acid gases. These last ingredients, from their comparatively small quantity, must be considered as entirely subordinate to the first. The physician has chiefly to attend to the nature of the impregnating gases, and the temperature of the vapour. From the very nature of the case, this form of administering mineral waters can only be practised at thermal springs, and



those, too, which possess a very elevated temperature. Not more than two or three of the European springs are fitted for the purpose, or possess the necessary apparatus, such as Karlsbad, Wiesbaden, Baden. The different forms of gaseous and vapour baths employed at different cold springs and thermal waters of an inconsiderable temperature, are of such doubtful efficacy when employed alone, without the aid of artificial subsidiaries, that they do not enter into our present plan, which is to consider mineral waters as medicinal agents in the form in which they are presented to us by the bountiful hand of Nature.

This is the most penetrating form in which mineral waters can be used externally, not merely acting with much more power upon the cutaneous organs than the water bath, but also producing infinitely greater changes upon the general system. The immediate effects which follow the use of the vapour-bath, are very analogous to the water-bath, though in a more exalted degree. Upon a person in health, the Karlsbad vapours produce an itching and prickling of the skin, especially of the extremities, which is succeeded by a sense of turgescence in the head, slight headach, and giddiness, which are relieved on the breaking out of the sweat, and go off entirely a few minutes after coming out of the bath. At this watering-place, the vapours can, in summer, be supplied of the temperature of from  $120^{\circ}$  to  $130^{\circ}$  F.; but patients can seldom bear more than a temperature of  $111^{\circ}$  for fifteen or twenty minutes. The temperature is very effectually regulated by graduating the quantity of vapour allowed to ascend the tube into the bath from the spring below. At Wiesbaden, the thermal vapours are previously collected into a cylinder, from whence they are distributed by means of tubes in different directions.

Mineral waters used in this form are particularly efficacious in cutaneous, gouty, and rheumatic complaints, either partially, when their action is desired to be more local, or generally, when they are also wished to affect the whole system. In the metastatic forms of some of

these disorders, they are very valuable, in recalling outwards and fixing the morbid virus. In ulcers and obstinate syphilitic affections, they may be also very useful. But still more precaution is necessary than in any of the other forms of using medicinal springs, from employing them in plethoric states of the system, and hence a few preparatory remedies are always advisable before commencing their regular use. Nor are they advisable in paralysis,—in tubercular diathesis,—or where there is a strong hereditary tendency to pulmonary phthisis,—and still less in hectic states.

At some of the watering-places on the continent, there have been contrived, as at Nenndorf, Baden, &c.<sup>1</sup> what are called *gas-rooms* or *cabinets*, which are chambers in which the air is impregnated more or less with the dry gases ascending from cold springs, or the vapours rising from thermal waters. Patients are recommended to breathe the atmosphere of these rooms in chronic bronchitis, obstinate hoarseness, or even common catarrh. But the dry gases inhaled in this way are usually too stimulant to be tried with safety even in a very dilute state.

Lastly, the vapours rising from thermal waters are occasionally employed in the form of douche, at a temperature of about 100° F., when it is wished to augment their power as local stimuli.

### SECTION III.

#### A FEW PRACTICAL DIRECTIONS TO BE OBSERVED DURING THE USE OF MEDICINAL SPRINGS.

THIS subject has been already so ably and elaborately handled, that it may perhaps be considered presumption in me to offer any observations upon it; but I am unwilling that this brief outline of the medicinal effects of

<sup>1</sup> Hufeland's Journal, l. st. 2. p. 68.

springs should be so incomplete as to pass by unnoticed this, one of the most requisite points to ensure their successful application.

1. *Rules for Drinking.*—They act with most effect when taken fasting, and early in the morning, about five or six o'clock. A single tumbler of the water may be taken every quarter of an hour, taking exercise in the open air, if the weather permits, otherwise under cover, between each dose. After the proper quantity, it may be useful to walk about for an hour before taking any food. In irritable habits, the water should not be drunk too quickly: the doses should be smaller, and repeated at longer intervals. Another way of diminishing the over-stimulant qualities of a mineral water, is to dilute it with warm milk, or heat it gently in the way formerly mentioned. All these methods, however, changing more or less the natural qualities, if it is not found to agree with the stomach or the constitution, it is much better to resort to one of a different quality or temperature.

Much difference of opinion has arisen upon the absolute quantity which a patient ought to take daily. This must depend very much both on the nature of the water, and the object which the practitioner has in view. Generally, however, their use should be commenced very gradually, not more than from two to four tumblers daily, which may be raised without inconvenience to ten or twelve, if its stimulant qualities are not very great, the patient not very weak, with regular exercise, and a due attention to the hygienic rules. The quantity must not be increased whenever they begin to produce much gastric oppression, cerebral or pulmonary congestions. The best signs of any given quantity agreeing with the system, are a slight increase in the natural evacuations by stool and urine. When the constitution has reached the point of saturation, their use should not be suddenly left off, but should be diminished as regularly as they were increased. Much will depend, too, upon the natural liking to the water. Those to which there is much repugnance, from their taste, or other sensible qualities,



will seldom be very beneficial. Only in certain cases is it advisable to take a second dose in the afternoon or evening.

In water which is drunk at a distance from the source, we ought to guard especially against the escape of gaseous matters, on too much exposure to the air, and the bottles ought to be kept well closed, and in a cool place. Every tumbler which is taken at the watering-place ought to be drawn fresh from the spring immediately before being drunk.

2. *Rules for Bathing.*—The best time for bathing is early in the morning, and, if the water is drunk at the same time, after the exercise which ought to follow the latter. If unavoidable circumstances should oblige a patient to bathe in the after part of the day, three or four hours at least ought to have elapsed since taking any food.

The temperature of the water may range from about 90° to 98° F., or even lower, in very irritable states of the system. Most frequently in debilitated states of the body, the nearer the bath approaches to blood-heat the better at first, and it may gradually be made cooler, when more tonic effects are wished. Artificial cooling or heating are not proper, but, if possible, a water should be selected whose natural temperature is of the degree wished for.

The time which a patient remains in the bath, must be regulated by his strength, the temperature of the water, and the object the physician has in view. A quarter of an hour may be considered as a medium time at first, which may be progressively raised to half or even a whole hour; and in some of the Swiss baths, it is not unusual for patients to remain for several hours together immersed in the water. In some chronic complaints, perhaps, this sort of amphibious life may be of use. The hotter or colder the bath, the shorter time should a patient remain in it, blood-heat being taken as the point of departure: generally a temperature somewhat lower than this standard is better borne than one

above it. In full plethoric habits, a much shorter time is allowable than in those of an opposite tendency.

The exact number of baths which may be necessary to effect a cure, can hardly be precisely laid down. Except in extraordinary cases, not more than one ought to be taken daily, so that probably about thirty is the maximum number. When very stimulant, probably once in every two days, three days, or even more seldom, is preferable. Immediately after the bath, the body should be covered up warm, to promote the flow of a gentle perspiration; and rest is preferable to motion. If the patient should feel exhausted after the bath, a glass of wine or a cup of coffee, chocolate, &c. may be allowed, before taking a regular meal, which ought not to be indulged in till the temporary effects have passed off.

All artificial additions to natural baths, with the view of increasing their virtues, or of medicating them, as it is called, are to be strongly reprobated. It is much better to resort at once to a spring which itself possesses all the conditions of quality and temperature which may be requisite. The variety and number of these agents is such, that it will be hard if some one may not be found adapted to every case. Besides, perhaps their efficacy, though mainly depending upon their stimulant qualities, is not to be ascribed so much to the violence of the stimulus, as to the blending together of many different ingredients, and their long-continued and persevering use.

3. *Hygienic and Dietetic Rules.*—The season during which mineral waters are employed medicinally, usually extends from the month of June to that of September. The summer season is selected, both on account of the greater constancy of the weather, the mildness of the air, and the general enlivening effects of this period, when all nature is full of animation. Much must, however, depend on the selection of the season, upon the nature of the disorder, and the local peculiarities of the watering-place. In some of the forms of erratic gout,

it may be advisable to resort to their use, even in the winter season.

No invalid ought to undertake a course of a mineral water without placing himself under the direction of a physician, who can alone regulate the quantity of water which ought to be employed, the form in which it should be used, and the duration of the course, as well as insure the observance of the proper auxiliary rules. And as the physicians practising at watering-places cannot be supposed acquainted with the constitution of their patients, they ought to be furnished with a short history of the cases of their patients, drawn up by the regular medical man previously in attendance.

The utmost regularity of habits ought to be observed by invalids on their resorting to a medicinal spring. Without the strictest attention to this, very little benefit can be expected to follow their use; and, to the neglect of this, much of the opprobrium thrown upon mineral waters, as medicinal agents, is, in all probability, to be ascribed. All the more violent impressions which tend to ruffle the serenity of the mind, should be carefully avoided; and, during the course, it would be well to abstain altogether from the pursuit of the ordinary avocations. The sleeping and waking hours must be partitioned with the greatest regularity. Late hours are to be avoided, and all midnight mental exertion.

Regular gentle exercise in the open air is of the utmost consequence, to insure the full benefits of a mineral water. Walking is proper only to a very short distance, from the tendency of the patient to become overheated. For visiting the romantic scenery which forms such an attraction at many watering-places, riding is preferable, either in a carriage, or, when this is impracticable, or, where a stronger degree of exercise can be borne, on horseback, mules, or asses. Exercise under cover is only proper when, from the extreme inclemency of the weather, or debilitated state of the patient, the former is impracticable.

With regard to diet, it is almost impossible to lay down any general rules, applicable to every case, as



much must depend upon the nature of the ailment, and the previous dietetic habits of the patient. A vegetable diet is, generally speaking, preferable in plethoric habits, or to assist the action of mineral waters of a cathartic, refrigerant, antiphlogistic quality. An animal diet, again, is more adapted in cases where the tonic powers of a spring are those of primary consequence. In other cases, a due mixture of both is the most proper. Meat which has been salted, smoked, and is very fat or heavy, is improper, as well as those vegetables which excite acid or the disengagement of gaseous matters in the stomach. Meat is therefore best roast or broiled. Vegetables should be boiled; they ought never to be taken raw. Nearly the same rules apply to the choice of wines: the very acid wines, or the heavy heating wines, are improper; the lighter French or Rhenish wines are the best; but in this, moderation in quantity must be still more rigidly adhered to than the quality. Spiritous liquors in every form are to be totally abstained from. The same rule may apply to malt liquors.

Some advise the efficacy of mineral waters to be assisted, as they call it, by the use of artificial remedies, to increase their strength as evacuants, or diminish their activity as stimulants. This practice is to be strongly reprobated. It is better at once to resort to a spring which possesses naturally the wished-for qualities, and to change it for another, when a slight modification in its properties becomes desirable.

In general, a course of mineral waters is not proper during the menstrual evacuation, or in the state of pregnancy. Nor are they proper in very old or very young persons. In all these cases, their stimulant qualities form a strong contra-indication to their use. Only some of the mildest laxative and refrigerant springs may be useful in the torpid state of the alvine excretion so common in pregnancy.



## APPENDIX.





# APPENDIX.

## No. I.

### HINTS TOWARDS AN AGENDA FOR MINERAL SPRINGS.

My object in the following observations is not to supersede the necessity of a complete analysis, nor are they in any wise intended for the masters of the hydro-analytic art. They are chiefly for the benefit of my brethren of the medical profession, who may possess neither the time nor the capability to institute an analysis of a mineral water with all the resources of modern chemistry, but who, by a few short preliminary essays, may be desirous of forming an opinion on the properties of a water proposed as a medicinal agent to combat a disease ;—and for the intelligent traveller, who has been too often deterred from turning his attention to the mineral and thermal waters of the countries he traverses, by the idea of their investigation requiring very profound chemical knowledge, and who might be disposed not to neglect this highly interesting branch of the natural history of a country, if he was acquainted with a compendious method of arriving at a few precise conclusions, or was provided with an Agenda which should briefly recall to his recollection, in the midst of his multifarious pursuits, the points chiefly demanding his attention.

For those, however, who may wish to obtain a more detailed account of the most advantageous processes for the analysis of a mineral water, I refer to :

1. A General Formula for the Analysis of Mineral Waters, by Dr John Murray, in the *Edinburgh Philosophical Transactions*, vol. viii. p. 259. 1818.
2. An Analysis of Sea Water, by the same, in the *Edinburgh Philosophical Transactions*, vol. viii. p. 205.

3. An Essay on the Analysis of Mineral Waters, by Richard Kirwan, Esq., 8vo. London, 1799.
4. Untersuchung der Mineral Wasser, von Karlsbad, von Tep-  
litz, und Königswart, von Prof. Jacob Berzelius, aus den  
Schriften d. Königl. schwed. Akad. d. Wiss. zu Stockholm,  
Übersetzt v. Dr. Gustav Rose; 8vo. Leipzig, 1825.
5. Chemische Untersuchung der Mineral Wasser, zu Geilnau,  
Fachingen u. Selters im Herzogthum Nassau, von Prof.  
Gustav. Bischof; 12o, Bonn, 1826.

### *I. Physical Relations of the Spring.*

1. Locality of the spring :
  - Geographical position. Distance from nearest town or other remarkable object.
  - Elevation above the level of the sea.
  - Distance from the sea or other large collections of salt or fresh water.
  - If in a plain, distance from the nearest hills or chain of mountains.
  - Mean annual temperature of its locality. Temperature of the different seasons.
  - Moisture or dryness of its climate. Annual quantity of rain.
  - Prevailing winds.
2. Geognosy of the spring :
  - Rock formation from which it emerges to the surface of the earth.
  - Geognostic structure of the surrounding country.
  - Is the rock surrounding the spring in a state of decomposition different from what can be ascribed to ordinary atmospheric causes?
  - If it rises in stratified rocks, are any derangements or dislocations observable in the strata?
  - Distance from, and relations of superposition to, the nearest unstratified or igneous rocks.
  - Nature and age of these igneous rocks.
  - Is it near the line of junction of two distinct formations, whether stratified or unstratified?
  - Position, geographical and geognostical, in relation to other mineral waters of the country.
  - Does it form part of a group of mineral waters, or is it to be considered as isolated?
3. Temperature :
  - Constancy throughout the changes of season and weather.
  - Constancy through a long succession of years.



- Is it unaffected by great physical phenomena, volcanic eruptions, earthquakes, &c. ?
4. Quantity of water discharged by the spring in a given time :  
Is it independent of the moisture or dryness of the air ?  
Is it constant through a long period of years ?  
Is it affected by earthquakes, &c. ?
5. Specific gravity :  
By the weight of a given volume of water, equal, for instance, to 1000 grains of distilled water at 60° F.  
By the hydrometer.  
Agreement of direct experiment with Kirwan's formula.
6. Sensible properties of the water :  
Smell,—variable according to weather,—sulphureous.  
Taste,—disagreeable,—saline,—carbonated,—sulphureous.  
Colour and transparency, the latter measured by the distance printed characters can be read through a stratum of a given thickness.
7. Gaseous bubbles discharged from the bed of the spring :  
Their nature.  
Probable quantity. Is it influenced by the barometric states of the air, or by unknown causes ? Sudden evolution of large quantities of gas.  
Do they form a superincumbent atmosphere over the basin of the spring ?  
Are similar gases evolved uncombined with water from any of the surrounding localities ?

## II. *Chemical Relations.*

1. Amount of solid matter obtained by evaporating a given quantity of the water to dryness. Weighed after having been exposed to a low red heat, and while still warm. Comparison of this with the specific gravity.
2. Loss of the dry residuum by alcohol of a given specific gravity.
3. Loss of the dry residuum by water.
4. Insoluble remainder.
5. Determination of the species and quantity of free and uncombined gases :  
By exposing to ebullition for a quarter of an hour over a spi-

rit lamp from 7000—14,000 grains of the water contained in a Florence flask provided with a bent tube. The gas to be collected in a graduated jar over mercury.

Carbonic acid is absorbed by a bit of caustic potash.

Sulphuretted hydrogen is indicated by a strong alcoholic solution of iodine.

Oxygen by the combustion of phosphorus in a small bent tube containing the gas.

During the ebullition, different insoluble carbonates, as of lime or magnesia, and the oxide of iron, are precipitated, which are to be collected.

6. Determination of the different species of salts contained in the mineral spring by means of reagents :

The substances usually found in mineral waters are the sulphates of soda, lime, and magnesia ; muriate of soda ; carbonates of soda, lime, magnesia, iron.

- a, Sulphuretted Hydrogen, or a Hydro-sulphate,* may be considered as present when it has a smell of rotten eggs ; gives a black precipitate by solutions of salts of lead, or of nitrate of silver ; and by the deposition of sulphur, on adding a few drops of nitric acid.
- b, Carbonic Acid Gas :* When it sparkles with agitation ; reddens litmus paper, but the red colour disappears after exposure to the air, or is prevented by previously boiling the water ; aqueous solution of baryta causes a precipitate which dissolves with effervescence in dilute muriatic acid ; when heated in close vessels which communicate with lime-water, the latter is rendered turbid.
- c, A free fixed Acid :* If litmus paper is reddened after boiling the water, and the red colour is permanent after exposure to the air.
- d, Sulphates :* If the nitrate or muriate of baryta forms a white precipitate, which remains undissolved in concentrated nitric acid.
- e, Muricates :* Nitrate of silver produces instantly a white flocculent deposit, which soon assumes a brown colour on exposure to light ; is not redissolved by a great excess of nitric acid, whilst a little caustic ammonia causes it to disappear entirely.
- f, Insoluble Carbonates,* as of lime, magnesia, &c. : On heating the water we see the formation of a pellicle, and when the liquor cools, a deposit which effervesces with an acid.
- g, Carbonate of Iron :* Boiling causes the precipitation of yellow flocci ; before boiling, a blue precipitate is caused by ferro-prussiate of potash, and a black by tincture of nut-galls.
- h, Sulphate of Iron :* If the same effects follow the addition

of ferro-prussiate of iron and tincture of nutgalls after boiling.

- i, *Carbonates of Soda or Potash*: After boiling violet paper or syrup of violets is tinged green, and turmeric paper is tinged of reddish brown.
- k, *Calcareous Salts*: Oxalic acid, or oxalate of ammonia, produce a white precipitate insoluble in acetic acid. These salts are not carbonate of lime, if the precipitate occurs after the ebullition and filtration of the water.
- l, *Magnesian Salts, not carbonates*: If, after having been boiled, filtered, and cooled, it is not rendered turbid by a solution of acid carbonate of soda, and becomes very turbid on warming the liquor, the sub-carbonate of magnesia is then precipitated in the form of white and light flocci;—by adding to the water carbonate of ammonia, which precipitates the lime, filter, and then add phosphate of soda, which yields a granular precipitate of the ammoniaco-magnesian phosphate; if no precipitate take place from the carbonate of ammonia, the water is to be treated with the phosphate of soda, as above.
- m, *Carbonate of Ammonia*: On submitting the mineral water to distillation, it gives an alkaline water.
- n, *Ammoniacal Salts, not the carbonate*: On evaporating slowly to dryness, and mixing the residue with quicklime, there is developed an acute and penetrating ammoniacal smell.
- a, *Nitrates*: On pouring in a solution of potassa till it ceases to cause a precipitate, filtering the liquor, and evaporating to dryness, we obtain a residuum which, thrown on burning coals, increases the activity of the combustion.
- p, *Silica*: On treating the residuum (4) with dilute muriatic acid, the silica remains as a white powder, not altered by a red heat, but immediately fusing with a little carbonate of soda.
- q, *Alumina*: Dissolve the residue after No. 2. in eight parts of water, filter and add oxalic acid, lime is separated, leaving magnesia and alumina in solution. Carbonate of ammonia precipitates alumina, and leaves magnesia. Pure ammonia throws down both alumina and magnesia. They may be separated by solution of potash, which dissolves the former, but not the latter.
- r, *Phosphates*: Evaporate the water almost to dryness; add an excess of lime-water; after the liquid has settled, decant the clear fluid, and dissolve the residuum in nitric acid, filter and neutralise the acid as near as possible with ammonia, on then adding a solution of the acetate of lead, there will be precipitated flocci of phosphate of lead.
- s, *Fluates*: On heating the insoluble residue in a platinum crucible, with concentrated nitric or sulphuric acids, a



plate of glass placed over the crucible exhibits traces of erosion.

7. Determination of the quantity of each of the salts contained in a given quantity of the water :

The quantity which should be employed for examination must depend upon the specific gravity that it possesses after its de-aeration. The smaller the specific gravity, the greater should be the quantity employed, and *vice versâ*. If the specific gravity amount to 1010 or more, then 7000 grains will be a sufficient quantity of it ; but if it amounts to 1001 or less, 70000 grains at least should be employed.

8. Is the chemical composition unaffected by season, atmospheric changes, &c. ?
9. Comparison with former analyses :  
Has the water experienced any change in the quantity and relative proportion of its ingredients ?
10. Comparison of its composition with that of the other mineral waters of the district.

### III. *Medicinal Relations.*

1. Immediate effects on being received into the stomach.
2. Permanent effects on the constitution :  
Diseases in which it is chiefly useful.
3. Appropriate doses and forms of employing it.
4. Duration of the course.
5. Precautions necessary while using it.

### IV. *History and Literature.*

#### No. II.

#### ON ARTIFICIAL MINERAL WATERS.

NUMEROUS attempts have been made ever since the commencement of the 17th century, to imitate the composition of natural mineral waters. The earlier of these were of course very far from attaining their object, in consequence of the want of the re-

quisite chemical knowledge. Bergman and Priestley, towards the end of the 18th, were the first who approached to any thing like a successful imitation. But we are above all indebted to the labours of Dr Struve of Dresden, who has exhausted on their preparation all the resources of the analytic and synthetic art, and has brought to light many important circumstances, formerly unattended to.

### 1. *Their Preparation.*

The object in view is to impregnate by art a given quantity of water with a certain amount of fixed and volatile matters, in as intimate a manner as possible.

Formerly in the days of Venel, Parker, Nooth, Paul, and Schweppe, nothing was thought necessary for this purpose except the appropriate employment of a simple compressing apparatus. Struve, however, brought to light the errors of most of these processes. Analyses were either employed which were inaccurate and uncertain, or substances were neglected which, from their quantities being small, were thought of little consequence. To arrive at any thing like accuracy in the results, there are a variety of considerations of much importance to be attended to.

No ingredient must be omitted in the artificial imitation, and each must be presented in the same quantity, and as much as possible in the same combinations, which have been detected by a careful analysis of the natural water. It is impossible to estimate the importance of apparently insignificant ingredients upon the composition and effects of the water, of lime, for example, of silica, of iron, &c.

A distinction must be made between mineral waters, which are drunk at the source, and those which are transported. The change of composition produced by the latter ought to be taken into account in the artificial imitation.

An excess, as well as a deficiency, of ingredients, must be guarded against. The mineral water should not be rendered too violent in its operation, by being charged with a larger quantity of gas, or otherwise differing from an exact counterpart of the natural water. Some difficulty attends the imitation of those springs which undergo changes in the amount of their impregnation. On this account, we cannot sufficiently applaud the determination of Struve, announced in his work, to institute a new analysis every year of the waters imitated in his establishment, in order to ascertain if they have undergone any change of composition.

The order in which the different substances are presented to the water, is a point of consequence. It is not unlikely that it modifies the composition, as it affects materially their sensible properties,—their smell and taste.

Temperature, both in respect to its degree and its duration,

ought to be carefully attended to, as it varies the effects of waters containing exactly the same kind and amount of ingredients.

When these precautions are attended to, solutions are obtained, which differ in none of their sensible properties from natural waters. The next question presents itself,—do they differ from them in chemical composition and medicinal efficacy?

## *2. Their Relation to Natural Springs.*

No impartial physician can deny that the artificial mineral waters as prepared by Struve, possess decided medicinal virtues. And consequently, it must be admitted that he has conferred an important benefit upon the healing art in preparing this class of remedies by a successful combination of all the resources of modern chemistry, with the view of serving as a substitute for the natural waters to those invalids who are prevented by the nature of their complaints, or other more imperious circumstances, from resorting to the natural spring. The question here is, therefore, not to estimate their general importance as therapeutical agents, but to inquire if, notwithstanding all the elaborate care which has been recently bestowed upon their preparation, they can be considered as perfectly identical in their composition and effects with natural waters. Chemists of eminence, as Kastner, Brandes, &c., have not hesitated to answer in the decided negative.

Notwithstanding all the labours of hydroanalysts to resolve the ingredients of mineral springs to their ultimate component elements, there are many which have never been detected at all, and perhaps some for which we possess no appropriate tests. It was long before iodine and manganese were discovered; and bromine and lithion were only demonstrated a very few years ago. The Karlsbad waters had been repeatedly analysed at different periods by distinguished chemists. Nay, even by Struve himself; yet Berzelius a few years ago succeeded in detecting no less than six new substances in these springs. Most of these substances it is true are in such small quantity, that many have considered them of no appreciable importance. But however small their quantity, they must certainly contribute to the aggregate effect of the whole. Some possess such active properties, that it is highly improbable that they are altogether inert. This applies particularly to the discovery of bromine by Daubeny in the brine springs of Ashby de la Zouch in England. And these circumstances render it highly probable that if waters which have acquired a certain medicinal reputation were more frequently and carefully analysed, substances would be detected of which we may have no suspicion. Besides, if we can trust the experiments of Gmelin and others, the rarer metals and salts are far from being insignificant remedies in point of activity.

But if the mere discovery of these ingredients is a task of such difficulty, how much less likely is it that we shall succeed in form-



ing an exact imitation of the waters in which they exist ; and of the numerous combinations and associations which they may form in the same fluid ? Does not a mere variation in the proportion of muriatic acid in corrosive sublimate and calomel, constitute all the difference between an active poison and a bland medicinal agent ? From this circumstance all the imitations of artificial mineral waters have not been equally successful, even in their most obvious sensible properties, much more in their medicinal effects. The Karlsbad water, for instance, as prepared by Struve, approaches pretty nearly to the natural, while the Ems water differs very considerably in taste, and is much stronger and more violent in its operation than the natural springs. If the observations which have been made in the body of this essay upon the combinations of the ingredients of mineral waters be at all well founded, we cannot conclude with Struve their perfect similarity to be a necessary consequence of identity in the results yielded by the chemical analysis of both. But Wetzler has even denied this identity in many which he examined.

Most of the physicians stationed to superintend different medicinal springs have thundered forth an unlimited anathema on artificial mineral waters, influenced probably by partiality or interested motives ; while many others have as enthusiastically exalted their virtues. To form, therefore, any thing like an unbiassed opinion upon their real value, we must resort to the testimony of men who, to ample experience of the effects of mineral waters, join a perfect freedom from interested motives. Their opinion, however, is equally divided. Hufeland does not consider them as perfectly identical either in composition and effects with natural waters ; while Wetzler and Vogel think that such is the case. Kreysig considers them as identical in their curative but not in their subsequent effects. Struve has cited in his book many testimonials in favour of his views. Osann considers them as nearly equal to natural waters in their predominant effects, although sometimes more violent, but that they often differ in their subordinate qualities. This is especially the case with the Selters water. Sometimes, however, the artificial are better borne in certain states of the body than the natural waters, which is a proof of the former being highly valuable medicinal agents, independently altogether of all considerations as to their identity or diversity from the latter.

Struve has never yet been able to succeed in the imitation of those waters whose medicinal efficacy does not correspond with the apparent insignificance of their mineral impregnation. He endeavours to explain the power of these springs by supposing that patients remain so long in the baths, which form large reservoirs constantly supplied with fresh water, that they are subject to a constant renewal of the active matters, and to the consequent maintenance of their active powers. But were this the case, a

marked difference ought to be observable between their efficacy in private baths and the public reservoirs, which is not the case.

Even admitting that the composition and effects of natural and artificial waters were in themselves perfectly similar, still the former would possess many local advantages of much importance in certain cases, and of which the latter are destitute. Such are change of scene, and air, regular exercise, agreeable objects of mental occupation, cessation of business, change of diet, &c.

In conclusion I shall merely observe that artificial mineral waters have experienced the fate of almost all newly introduced remedies. By some their value has been much exaggerated; while by others they have been as much depreciated. As medicinal agents they seem to possess undoubted value, and may be well adapted for many forms of disease; but whether they are counterparts of natural mineral springs, is what, in the present state of our knowledge, I should hesitate admitting. There are, however, circumstances formerly alluded to, which render it impossible or extremely inconvenient to resort to the source itself; it therefore becomes our duty to enquire briefly,

### 3. *Advantages of Artificial and Natural Mineral Waters.*

*Artificial* mineral waters possess the advantages of being modified according to the circumstances of the case, being either stronger or weaker, or even of a composition such as is not to be found in nature.

They can be used at much less expense, and without so great a loss of time as is entailed by a visit to a watering place:

The benefits of several mineral waters situated in nature at great distances from each other, may be simultaneously enjoyed according to the wants of the patient:

The certainty of a constancy of chemical constitution in the water employed, under all circumstances of weather, season, &c., if they are rightly prepared.

The advantage of the cure being conducted under the superintendence of the ordinary medical attendant of the patient, who must be best acquainted with his constitution and the nature of his disorder.

*Natural* mineral waters have the advantage of climate, local beauties, society, &c.

A change of habits and occupations, often an indispensable condition for the cure of chronic diseases:

The journey to the watering place, and the exercise with which their use is always accompanied:

The use of the waters in all the perfection of their composition:

The various forms in which they can be administered both internally and externally.

#### 4. *Principal Establishments for their Use.*

These require not merely the necessary apparatus for the preparation of the water, but also appropriate buildings for its administration in its various forms. There was formerly a manufacture in this country at London by Schweppe, by Paul at Geneva, by Fries at Ratisbon, and by Ziegler at Winterthur. But at present the following are the principal of these establishments.

The *Brighton German Spa* in this country. This institution was opened in the year 1825, and is under the superintendence of Mr Walcker, a native of Germany; and we are informed that the apparatus is excellent, that cleanliness and regularity reigns in all the arrangements, and that the utmost facilities are afforded for the administration of all the celebrated continental mineral waters. From its position, this establishment is calculated to be very beneficial to the inhabitants of London, as, with the advantage of an excellent climate, the use of sea-bathing can be conjoined with that of the artificial mineral waters. The pump-room is open from six to eleven a. m. between the months of May and November. Among the waters prepared at this establishment may be enumerated those of Carlsbad, Ems, Marienbad, Franzensbad, Pyrmont, Spa, Selters, Geilnau, Saidschütz and Püllnas.

*Tivoli* in the Chaussee d'Antin at Paris, founded in the year 1799. There are, according to the most recent intelligence (Kopp. 1826), no less than fourteen manufactories of artificial mineral waters in the French metropolis; but this establishment furnishes two-thirds of the whole quantity used there, as well as in the rest of France. It is provided with appropriate rooms, at different prices, for the reception of invalids, supplied with all the apparatus for baths, fumigations, galvanism, &c., as well as a garden for exercise. The chief waters of France, Germany, and Italy are here furnished; the artificial Bareges sulphurous water baths are those in most common use. It is at present under the superintendence of Dr Andeoud, the successor of Jurine and Tryaire.

*Oleggio* in Italy. This establishment, which is one of the most complete in all its arrangements, was established about ten years ago by Signior Paganini. It is situated on the summit of a hill near the town of this name, in one of the most delightful regions of Piedmont, near the road over the Simplon, about four miles from the Lago Maggiore, and eight from the celebrated Borromean Islands. This agreeable site contributes much to render it a frequent resort. Besides the laboratory for the preparation of the waters, there are rooms for the patients, apparatus for baths, fumigation, the affusion, a kitchen and botanical gardens, a coffee-room, a restaurateur, a library, and a small theatre. All the chief mineral waters of Italy, Germany, and France, are administered. According to Paganini, in the year 1825, there were 318 patients admitted into this establishment, of which 255 were cured, 58 re-



mained in the establishment, and 5 died; 168 of the number laboured under chronic disorders, 58 under cutaneous affections, 45 syphilitic and mercurial affections; 34 different forms of neuralgia, and 13 insanity.

*Stockholm* possesses an establishment for the preparation of the *Karlsbad* water, according to the analysis of *Berzelius*. From 800 to 900 persons can, if necessary, be daily supplied with the water.

The last set of establishments are those which have been set on foot in different parts of Germany under the directions of *Struve* himself, at *Dresden*, *Leipzig*, *Berlin*, *Königsberg*, *Warsaw*, and *Moscow*. They furnish the waters only for drinking. In all, by means of agreeable gardens, promenades, music, &c., it has been attempted to indemnify the invalids as much as possible for the want of the natural springs. The number of patients is in general very considerable; it amounted at *Dresden*, in summer 1826, to 700, at *Leipzig* to 500, at *Berlin* annually from 500 to 650, and at *Warsaw* in 1825 to 900.

### No. III.

#### MINERALIZED MUD BATHS.

FROM the earliest times, the deposit of many mineral and other waters has been resorted to as a medicinal agent. *Pliny*<sup>1</sup> celebrates the efficacy of simple mud applied externally to the body, and *Galen* notices this use of the mud of the river Nile<sup>2</sup>.

It consists either of the simple deposit of the water alone, or of the deposit mixed with a certain proportion of earthy matters. The first of these is denominated by *Duchanoy* under the title of *Mares*, and the second under that of *Boues*<sup>3</sup>. All the varieties of mineralised mud are designated by the Italians under the common name of *Lutatura*<sup>4</sup>.

The mineralised mud contains in larger quantity, and in a more concentrated form, the solid saline matters entering into the composition of the mineral water: but many of these ingredients have also experienced important chemical changes; those which were soluble in the water have become insoluble in the mud; the carbonated earths, for example, having parted with all their excess of carbonic acid, the iron is converted from the protoxide into the peroxide. With regard to the gaseous matters, most of those contained originally in the water have escaped, and new ones are generated, the product of the reaction of the elements of the mud, or of a process of partial fermentation, such as carburetted hydrogen. But, above all, one of the most important differences by

<sup>1</sup> Hist. Nat. lib. xxxi. cap. 32.—<sup>2</sup> *Baccius* de Thermis, cap. 16, 17, 18. pp. 78, 79.—<sup>3</sup> *Patissier*, Manuel, p. 74.—<sup>4</sup> *Bertini*, p. 56.

which they are distinguished from the baths of mineral water, is the large proportion of organic matters. The high temperature and the specific gravity of the mineral mud will also contribute materially to exalt the activity of its component parts.

Three principal varieties of the mineralised mud may be distinguished: that consisting of the simple deposit of mineral waters highly charged with solid matters, and freely exposed to the air, which is composed almost solely of metallic and saline particles, as at most chalybeate and brine springs: that in which the deposit is mixed with organic, chiefly vegetable matters, derived from the soil, and of gases derived from their fermentation; of this description are the mud baths of Marienbad, Franzensbad, &c.: and that where, besides the saline and metallic particles, there is a certain quantity of gelatinous azotised matter. This is found exclusively in thermal waters and those which disengage azotic gas, and are generally of the sulphureous classes, as many in Italy and the south of France.

The mineral mud is of course entirely an external remedy in the form of bath, either general or local. The effects of the simple application of the mud to the affected part are often rendered more active by friction, or by using, as a cleansing bath afterwards, instead of common water, the douche of mineral water.

The latest division of the mineral mud baths, according to their medicinal effects, is that by Osann<sup>1</sup>, into—1. The sulphureous: 2. The carbonated: 3. Ferruginous: 4. Saline: 5. Earthy: 6. Gelatinous.

I shall briefly state the principal physical, chemical, and medical qualities of each, with the principal places where they are employed.

1. *Sulphureous Mineralised Mud.* It is principally obtained from cold and hot sulphureous springs. It has a penetrating sulphureous smell, and a peculiarly unctuous feel. Sulphur is its most active ingredient in the form of oxidised sulphur, hydrothionates, and sulphuretted hydrogen: this is associated with alkaline and earthy salts, sand, clay, extractive, oxide of iron, all of which are direct products of the sulphureous water.

The following is a tabular view of the composition of the mineralised mud of three of the principal sulphureous waters.

That of the thermals of Acqui in Piedmont contains, according to Mojon,

Silica,	.	.	.	.	.	.	.	.	0.46
Alum,	.	.	.	.	.	.	.	.	0.22
Oxide of iron,	.	.	.	.	.	.	.	.	0.05
Carbonate of lime,	.	.	.	.	.	.	.	.	0.12
Sulphate of lime,	.	.	.	.	.	.	.	.	0.07
Loss,	.	.	.	.	.	.	.	.	0.08
									<hr/> 1.00

<sup>1</sup> Darstellung, p. 385.

That of Eilsen in Germany, according to Westrumb,

Sulphur and mineral resin, . . . . .	0.12
Sulphate of lime, . . . . .	1.20
Hydrothionate of lime, . . . . .	1.20
Sulphur, . . . . .	4.25
Lime, . . . . .	3.00
Alumina, . . . . .	5.20
Vegetable fibre, . . . . .	6.60
Slimy matter, . . . . .	1.12
Sand and carbonaceous matter, . . . . .	21.36
Water, . . . . .	55.00
	<hr/>
	99.25

And that of Günthersbad in Thuringia, according to Bucholz, in 1000 parts of the dry mud,

Carbonate of lime, . . . . .	143
Carbonate of magnesia, . . . . .	5
Ferruginous alumina, . . . . .	42
Oxide of iron, . . . . .	3
Sulphate of lime, . . . . .	10
Waxy matter, . . . . .	4
Extractive, . . . . .	0.75
Carbonaceous matter, . . . . .	110
Sandy particles, . . . . .	492.25
	<hr/>
	800

In medicinal effects, this species of mud resembles baths of sulphureous waters, but is more penetrating, particularly in those which possess a high temperature. The dominant effects of the sulphur are chiefly modified by the oxide of iron and extractive matter.

The diseases in which this mineralised mud is employed are obstinate cutaneous eruptions and old ulcers; gouty and rheumatic contractions and swellings; old syphilitic disorders, arthritis syphilitica; and scrofulous glandular swellings.

The principal sulphureous mud baths are—

*Abano* near Padua in Lombardy, which has been celebrated since the times of Martial, Ammianus Marcellinus, Claudian, and Pliny. It is prepared by mixing fine clay and sand, which is placed in a pit or wooden trough, over which the thermal water is allowed to flow for some months. After having been used for the patients it is spread as manure over the fields. The mode of employing it is to spread a linen cloth with a layer of mud three or four inches thick, in which the whole body of the patient, or merely the affected part, is enveloped, and which is renewed as soon as the temperature falls. The same mud is not used more than once.



*Acqui* in the valley of the Bormida in Piedmont. The mud is taken from the bottom of several large reservoirs filled with the thermal water. Its temperature varies from 93° to 117° F. An hour is the common time that its application lasts.

*St Amand* in Belgium. Is used of the temperature of 77°.

*Eilsen* in the principality of Lippe: *Nenndorf* in Hesse: *Fiestel* in Westphalia: *Meinberg* in Lippe: *Northeim* in Hanover: *Gunthersbad* in Thuringia: *Baden* in Austria.

2. *Carbonated Mineralised Mud.* This consists of the deposit of ferruginous mineral waters mixed with vegetable earth, and vegetable matters in a state of decomposition, peat-bog, moss, &c. It has usually a bituminous and slightly sulphureous smell. The iron and sulphur, with which the vegetable matter is mixed, have the principal share in modifying its properties; the former is often in the state of sulphate, and associated with a certain quantity of alum. Its gaseous matters are, besides a little sulphuretted hydrogen, some carbonic acid.

The following is the composition of some of the carbonated muds used medicinally.

That of *Marienbad* in Bohemia consists, according to Reuss, in 10,000 parts of

Silica and clay,	602.11
Carbonised vegetable matter, with water,	4006.91
Pure Soda,	0.23
Sulphate of Soda,	0.85
Muriate of Soda,	0.06
Sulphate of Magnesia, }	14.43
Sulphate of Lime, }	
Oxide of Iron,	5302.53
Water,	5300.00

That of *Gleissen* in Brandenburg consists, according to John, in 100 parts of the dry mud, of

Bituminous, azotised, coaly matter, insoluble in water,	90.25
A peculiar azotised coaly matter, soluble in water,	2.50
Resinous matter,	traces
Sulphate of Lime,	3.50
Peroxide of Iron,	
Sulphate of Iron,	
Muriate of Potash,	
Carbonate of Lime,	
Alumina,	traces
Magnesia,	
Ammonia,	traces
Insoluble earths, with gypsum and oxide of iron,	4.00

And in that of *Muskau* in Lusatia, according to *Hermbstädl*, 2000 grains of the mud contain

11.5 cubic inches of gaseous matter, viz.

Carbonic Acid, . . . . .	9.5
Carburetted Hydrogen, . . . . .	0.5
Hydrothionic Acid, . . . . .	1.5

27.0 grains of matter soluble in water, viz.

Soluble humus-extractive, . . . . .	15.0
Sulphate of Lime, . . . . .	1.5
Muriate of Potash, . . . . .	3.0
Muriate of Soda, . . . . .	3.5
Sulphate of Soda, . . . . .	2.5
Sulphate of Magnesia, . . . . .	1.5

The ashes of the mud contained

Muriate of Soda, . . . . .	3.0 grains.
Sulphate of Soda, . . . . .	3.5
Ferruginous Alumina, . . . . .	33.5

This species of mineral mud is recommended in chronic cutaneous affections and ulcers,—ulcers with a too copious discharge—besides other diseases, such as palsies, contractions, neuralgiæ, where it is of more doubtful efficacy.

The chief carbonated mineral mud-baths are *Marienbad* and *Franzensbad* in Bohemia, *Gleissen* in Brandenburg, *Muskau* in Lusatia, *Driburg* and *Pyrmont*, *Audinac* in France.

3. *Ferruginous mineralised Mud*.—Resembles the former, but, from its larger proportion of iron, is distinguished by its more astringent qualities, and has been recommended in all cases of local debility and atony.

The chemical composition of that of Loka is, according to Berzelius, in one pound, of gaseous matter

Carbonic Acid and Sulphuretted Hydrogen, . . . . .	2.6 cub. in.
Atmospheric Air, . . . . .	0.3
Carburetted Hydrogen, . . . . .	0.8
	<hr/> 3.7

40 parts of the dried mud contain

Extractive, . . . . .	0.45
Sulphate of Lime, . . . . .	0.10
Sulphate of Iron, . . . . .	0.05
Combustible matter, . . . . .	14.02
Oxide of Iron, . . . . .	1.72
Clay, . . . . .	0.75
Carbonate of Magnesia, . . . . .	0.20
Silica, . . . . .	22.32
Carbonate of Lime, . . . . .	trace.

100 parts of that of Piestan in Hungary contain, according to Scholz,

Silica, . . . . .	62
Alumina, . . . . .	12
Oxide of Iron, . . . . .	11
Humus, . . . . .	1
Lime, . . . . .	5
Water, . . . . .	9

When rubbed on the skin, this species of mineral mud often excites a peculiar eruption, a pricking sensation, and an agreeable glow.

The principal ferruginous muds are those of *Loka*, in the district of Oerebrosch in Sweden; of *Medivi* in East Gothland, in the same country; of *Piestan* in Hungary, which is used of the temperature of 97°, and is thought to be very efficacious in dispelling rheumatism.

The ochry deposit of common chalybeates is sometimes, though rarely, applied externally, in the form of plaster, in indolent and relaxed ulcers.

4. *Saline mineralised Mud*.—It is the product of the evaporation of saline or brine springs, and of salt-lakes. Muriate of soda is the chief ingredient, associated with sulphates and muriates of the alkalis and earths. In its effects, it approaches that of saline springs locally applied, but is much more penetrating. Occasionally there is a small intermixture of sulphuretted hydrogen.

The principal are,

*Sacker*, a salt-lake in the Crimea, the evaporation of which in July and August, yields a deposit very much used as a medicinal agent. According to Serre, 1000 parts consist of

Lime, Magnesia, and Alumina, mixed with Silica and Iron, . . . . .	687.0
Muriate of Soda, . . . . .	225.0
~~~~~ of Lime, . . . . .	17.0
~~~~~ of Magnesia, . . . . .	45.0
Sulphate of Lime, . . . . .	6.0

Patients flock thither from all parts of the Crimea, and the cure lasts from eight to thirty days, and is conducted by the Tartar priests. The following is the method of using it detailed by Lang<sup>1</sup>. Early in the morning a pit is dug, where the mud is freest from hard bodies and saline crystals. In this the patient is laid about noon, and covered up to the neck with the mineral mud. He is protected from the sun's rays by a parasol or cloth. He remains from two to three hours in this position, during which time the mud is renewed twice or thrice. His thirst is quenched by wine and water, or quass. After the bath, the patient is laid upon a straw-mat, and his whole body washed with the salt water of the adjoining lake. This process is considered by the natives a sovereign remedy for chronic gout and rheumatism, abdominal ob-

<sup>1</sup> Scherer's *Rusischen Heilq.* p. 184.



structions, glandular swellings, chronic cutaneous eruptions, and even intermittent fevers.

*Elmen*, near Salza, in the county of Magdeburg; *Ischl* in Salzburg; *Bourbon l'Archambault* and *Bourbonne les Bains* in France.

5. *Earthy mineralised Mud*.—This consists of the brownish, soapy, sinter-like matter deposited by hot and cold springs rich in carbonated earths, or of the frothy matter obtained by boiling many springs (the *Badeschaum* of the Germans).

The principal of these baths are,

*Schlangenbad* in Nassau; *Wiesbaden*, in the same duchy, celebrated in the time of the Romans, when it was even exported to Rome itself<sup>1</sup>; *Ussat* in France, which consists, according to Pattissier, in 100 parts of

Alumina,	.	.	.	.	.	40
Carbonate of Lime,	.	.	.	.	.	20
Sulphate of Soda,	.	.	.	.	.	10
Oxide of Iron,	.	.	.	.	.	2
Silica,	.	.	.	.	.	28

*Rehburg* in Hanover, containing, in 200 parts, according to Westrumb,

Carbonate of Lime,	.	.	.	.	182
Alumina,	.	.	.	.	6.5
Oxide of Iron,	.	.	.	.	8
Silica,	.	.	.	.	2.5
Copper,	.	.	.	.	1

*Hofgeismar* in Hesse, according to Wurzer, contains, besides carbonate of lime,

Fluate of Lime,	.	.	.	.	0.004
Alumina,	.	.	.	.	0.009
Silica,	.	.	.	.	0.022
Oxide of Iron,	.	.	.	.	0.050

6. *Gelatinous mineralised mud*.—This is a product of thermal waters, of the active ingredient of which a more detailed account has been given in the body of this Essay at p. 43. It is noticed here, from its being used as an external application, like the other deposits of mineral waters. Even in Pliny, we find, “*musculus, qui in aqua fuerit, podagris illitur prodest*”<sup>2</sup>.

At *Gastein*, *Baden* in Baden, *Neris* and *Dax*, this *Uva thermalis*, as it is called by some, is used in scrofulous sores, running tetters, &c.

<sup>1</sup> The *Pilæ Mattiacæ*, see Martial, Epigram. lib. xiv. epigr. 27. — <sup>2</sup> Hist. Nat. lib. xxxi. cap. 38.

## No. IV.

OBSERVATIONS ON THE TEMPERATURE OF THE EARTH  
IN PRUSSIA.

SINCE writing the above, I have seen an account by M. Gerhard<sup>1</sup> of a pretty extensive series of observations made at the instance of Baron Alexander Humboldt, in several of the mines of Prussia. But although every precaution seems to have been taken to insure accurate results, by sinking the thermometers to the depth of from two to four feet in the rock forming the walls and floors of the shafts and galleries, and in selecting situations for the bores remote from workmen, currents of air, &c. Still they are insufficient to arrive at general results on the increase of temperature in the interior of the earth, on account of the numerous and great deviations of the means of the observations. The following is a synoptical Table of these observations, reduced to English measure, in order that they may be susceptible of direct comparison with those cited in the text.

In obs. 1. The thermometer bore was sunk in dolomite limestone.

In obs. 2. Thermometer of the superior station was in slate-clay ;  
that of the inferior in coal.

In obs. 3. Both thermometers were in coal.

In obs. 4. Superior thermometer in sandstone ; inferior in coal.

In obs. 5. Both thermometers in copper-slate ?

In obs. 6. Both thermometers in sandstone.

In obs. 7. Superior thermometer in indurated clay ; inferior in  
the *rothliegende*.

In obs. 8. Superior thermometer in slate-clay ; inferior in slaty  
sandstone.

In obs. 9. Superior thermometer in alluvial sand ; inferior in the  
*rothliegende* ?

In obs. 10. Both thermometers in greywacke.

In obs. 11. Superior thermometer in alluvial sand ; inferior ther-  
mometers in slate-clay.

<sup>1</sup> Poggendorff's *Annalen der Physik*, xxii. 497. 1831, No. 8.





## TABLES.



Vicar's Bridge, Pullnas,	Scotland. Bohemia.	0 4.63	203.00 182.83	0.18 17.20	0.16 75.00	2.56 20.38	13.2 45.45	103.00 0	563.10 341.1	Connell, 1831. Struve.	Potash, a trace. Potash 3.55. { Nitric acid 7.75; phosphoric acid; pot- ash 3.61; strontian 0.93; alumina; ox- ide of manganese. Traces of iodine & bromine by Daubeny.
Saidschutz,	Ditto.	4.81	97.43	1.43	14.20	6.02	41.92	trace	177.4	Ditto.	
Leamington (Royal Pump), Harrowgate (old sulphur well),	England. Ditto.	0 1.20	20.80 76.83	71.90 76.83	57.90 60.50	12.00 4.47	4.95 1.94	1.09 0	153.9 145.4	Thomson, 1830. Scudamore, 1819.	
Airthrey (first spring), Cheltenham (old well), Hartfell aluminous chalyb. Isle of Wight,	Scotland. England. Scotland. England.	0 0 0 0	4.25 11.95 63.23 48.53	76.46 50.65 0 2.95	32.10 45.80 0 6.85	32.50 4.26 0 5.68	0.31 1.22 0 0.82	0 trace 40.00 14.60	127.4 111.6 101.3 83.21	Thomson, 1828. Scudamore, 1819. Thomson, 1828. Marcet.	Trace of iodine by Daubeny. Alumina 5.10. Alumina 7.77.
Marienbad (Ferdinands- quelle), Dunblane (north spring), Vals,	Bohemia. Scotland. France.	9.52 0.30 22.48	27.60 2.23 29.49	9.50 33.55 3.00	33.05 15.30 33.34	2.87 14.04 1.60	1.67 0 0.22	0.12 0.23 0.06	86.18 63.21 61.17	Steinmann, 1820. Murray, 1814. Berthier.	{ Phosphoric acid, lithion, strontian, alu- mina, manganese, by Berzelius.
Blinn, Franzenbad (Franzens- brunn), Pitcaithly, Roisdorf,	Ditto. Scotland. { Rhenish Prussia. }	5.44 0.30 6.76	18.50 0.73 2.50	6.21 27.20 9.70	26.70 8.50 16.00	1.26 13.99 1.78	0 0 1.33	0.37 trace 0.07	55.80 46.95 38.11	Tromsdorff, 1820. Murray, 1814. Bischof, 1826.	{ Phosphoric acid, lithion, strontian, alu- mina, manganese, by Berzelius.
Epsom, Selters (Nieder), Fachingen, Soden, Mofatt,	England. Nassau. Ditto. Ditto. Scotland.	2.50 5.37 11.49 3.35 0	14.80 0.18 0.12 0.07 2.80	4.21 9.92 2.63 12.30 13.60	5.64 16.06 15.63 10.72 12.75	11.80 1.37 1.83 4.08 0.63	0 1.00 1.09 0.06 0.26	0 0.12 0.07 0.08 0	37.94 34.60 32.93 30.89 30.03	Daubeny, 1830. Bischof, 1826. Ditto. Meyer, 1820. Thomson, 1828.	Trace of bromine. Phosphoric acid 0.19. Phosphoric acid 0.005.
Pymont,	Germany.	4.03	9.83	0.99	1.29	8.56	1.98	0.36	27.89	Struve.	{ Phosphoric acid, potash, strontian, man- ganese.
Marienfels,	Nassau	4.83	0.18	1.88	3.42	2.20	1.27	0.10	15.99	Kastner.	{ Potash 1.19; strontian, manganese, phos- phoric acid.
Strathpeffer (pump-room), Gellnau, Weilbach, Hartfell Spa, Langenschwalbach (Wein- brunn), Spa,	Scotland. Nassau. Ditto. Scotland. Nassau.	0 6.00 3.61 0 3.84	9.32 0.07 0.81 2.76 0.12	2.17 0.18 1.31 3.05 0.12	6.13 5.08 4.60 2.30 0.34	2.33 1.46 1.55 2.30 1.55	0.30 1.40 2.05 0 1.95	0 0.13 0 2.49 0.67	15.36 14.66 14.40 9.95 8.58	Thomson, 1828. Bischof, 1826. Creve, 1810. Thomson, 1828. Kastner, 1829.	Potash? Phosphoric acid 0.19. Sulphur-resin 0.48. Alumina, a trace. { Potash, lithion, iodine, strontian, alu- mina, manganese, phosphoric acid.
Carlsbad (Sauerling), Tunbridge, Malvern,	Germany. Bohemia. England. Ditto.	6.63 0.28 0.20 0.32	0.51 0.13 0.14 0.14	0.33 0.07 0.29 0.08	0.92 0.28 0.19 0.55	0.74 0.16 0.39 0.03	0.72 0.06 0.02 0.02	7.90 0.06 0.38 0.04	5.92 1.42 1.32 1.01	Struve. Berzelius, 1822. Scudamore, 1816. Philip, 1805.	{ Phosphoric acid; potash 0.51; manganese. Oxide of manganese.



## TABLE II.

255 OF THE MOST CELEBRATED MINERAL AND THERMAL  
SPRINGS,

*Arranged according to the Rock Formations from which they emerge to the surface of the Earth.*

Those marked \* are Thermal.

FROM PRIMITIVE ROCKS.		
NAME.	GEOGRAPHIC POSITION.	GEOGNOSTIC POSITION.
*1. Bonnes, . . .	Valley of Ossan, Upper Pyrenees,	Granite. One of springs from transition <i>cal-schiste</i> .
*2. Cauterets, . . .	Upper Pyrenees, . . .	Small grained granite, with steatite.
*3. Bagneres de Lu-	Pyrenees, . . . . .	Granite.
chon, . . . . .		Granite.
*4. Ax, . . . . .		Granite.
*5. Vic en Carlades,	Foot of Mount Cantal, France,	Granite.
6. Vals, . . . . .	Department of Ardèche, France,	Granite.
*7. Caldas, . . . . .	Portugal, . . . . .	Granite.
*8. Mantegas, . . . . .	Ditto, . . . . .	Granite.
*9. Eaux Chaudes, . . . . .	Valley of Ossan, Pyrenees, . . . . .	Granite.
*10. Oletta, . . . . .	Eastern Pyrenees, . . . . .	Granite.
*11. Karlsbad, . . . . .	Bohemia, . . . . .	Granite.
*12. Warmbrunn, . . . . .	Silesia, . . . . .	Small grained granite.
*13. Trincheras, . . . . .	Province of Venezuela, South America, . . . . .	Large grained granite.
*14. Jumnotree, . . . . .	Sources of the Ganges, Hindostan, . . . . .	Granite.
*15. Gastein, . . . . .	Country of Salzburg, European Alps, . . . . .	Granite and gneiss.
16. & 17. Lieberwertha and Flinsberg,	Chain of the Riesengebirge, . . . . .	Granite, gneiss, & mica-schist.
18. Malvern, . . . . .	England, . . . . .	Granite, syenite, & greenstone.
*19. Landeck, . . . . .	Silesia, . . . . .	Gneiss.
*20. Onoto, . . . . .	Province of Venezuela, South America, . . . . .	Gneiss.
*21. Mariano, . . . . .	Ditto ditto, . . . . .	Gneiss.
22. Bilin, . . . . .	Bohemia, . . . . .	Gneiss.
23-26. Griesbach, Petersthal, Antogast, Riepsdau, . . . . .	Grand Duchy of Baden, Black Forest, . . . . .	Gneiss.
*27. St Nectaire, . . . . .	Auvergne in France, . . . . .	Gneiss in a state of decomposition.
*28. Wildbad, . . . . .	Wurtemberg, . . . . .	Primitive rock of Black Forest. Gneiss?
*29. Chandes Aigues,	Department of Cantal, France,	Gneiss, mica schist, and clay-slate formation.
*30. St Sauveur, . . . . .	Valley of Bastan, Pyrenees, . . . . .	Mica-schist.
*31. Quindiu, . . . . .	Andes of Popayan, S. America,	Mica-schist.
32. Tiszoltz . . . . .	County of Gömör, Hungary, . . . . .	Junction of gneiss and mica-schist with greywacke slate.
*33. St Vincent, . . . . .	Piedmont, . . . . .	Talcose mica-schist.
*34. Schlangenbad, . . . . .	Duchy of Nassau, . . . . .	Talcose and chloritic slate.
35. & 36. Cronberg and Eltvile, . . . . .	Ditto ditto, . . . . .	Talcose and quartz chlorite slate.
37. Oberlahnstein, . . . . .	Ditto ditto, . . . . .	Ferruginous chlorite slate.
*38. Baresges, . . . . .	Upper Pyrenees, . . . . .	Calcariferous clay-slate.
*39. St Didier, . . . . .	Piedmont, . . . . .	Limestone alternating with mica-schist.
*40 & 41. Viray and Aequi, . . . . .	Ditto, . . . . .	Limestone.
*42. St Gervais, . . . . .	Savoy, . . . . .	Foliated feldspathic rock.

FROM TRANSITION ROCKS.		
NAME.	GEOGRAPHIC POSITION.	GEOGNOSTIC POSITION.
43. Ruckershausen,	Duchy of Nassau, . . .	Greywacke.
43. & 44. Sauetherthal and Sauerborn, . .	Ditto ditto, . . .	Greywacke.
45. & 46. Braubach and Dinkhold, . . .	Ditto ditto, . . .	Granular greywacke.
47. & 48. Llandrindod and Buallt, . . .	Radnorshire, England, . . .	Greywacke and slates.
*49. & 50. Aachen and Burtscheid, . . .	Lower Rhine, . . .	Junction of greywacke with black compact limestone.
51. Wildungen, . . .	Near Cassel, . . .	Junction of greywacke and clay- slate with variegated sandst.
52 & 53. Aigle and Bex,	Switzerland, . . .	Greywacke and limestone.
*54. Bertrich, . . .	Lower Rhine, . . .	Greywacke slate.
*55. Ems, . . .	Duchy of Nassau, . . .	Siliceous greywacke slate.
56. Marienfels, . . .	Ditto ditto, . . .	Ash-grey greywacke slate.
57. Geilnau, . . .	Ditto ditto, . . .	Greywacke slate.
57-60. Langenschwal- bach, Ramschied, Geroldstein, Fisch- bach, . . .	Ditto ditto, . . .	Greywacke slate and clay-slate.
61. Fachingen, . . .	Ditto ditto, . . .	Clay-slate.
62. Selters, . . .	Ditto ditto, . . .	Clay-slate and greywacke at junction with greenstone.
63. Salzbrunn, . . .	Silesia, . . .	Clay-slate near red sandstone formation.
*64. Cambo, . . .	Lower Pyrenees, . . .	Black calcariferous clay-slate.
*65. Bourbon l'Archam- bault, . . .	Department of the Allier, France,	Transition schist and compact limestone.
*66. Bagneres de Bi- gorre, . . .	Upper Pyrenees, . . .	Compact grey limestone with iron pyrites.
*67. Bourbon Lancy,	Dep. of Saone and Loire, France,	Limits of granite, mountain limest., and coal formation.
68. Spa, . . .	Lower Rhine, . . .	Junction of transition rocks with coal formation.
FROM ANCIENT VOLCANIC ROCKS.		
*69. Budos, . . .	Transylvania, . . .	Trachyte.
*70. Maschuka, . . .	Caucasian Mountains, . . .	Trachyte and calc-sinter.
*71. Eisenberg, . . .	Ditto ditto, . . .	Trachyte.
72. Dreiser Weiher,	Eifel Mountains, . . .	Trachyte.
73 & 74. Biresborn and Geroldstein, . . .	Extinct Volcano of Geroldstein,	Trachyte.
75. & 76. Tonnistein, Heilbroun, &c., . .	Lake of Laach, . . .	Trachyte.
77. Parad, . . .	Mount Matra, Hungary, . . .	Junction of trachyte with sand- stone of plain.
*78. Teplitz, . . .	Bohemia, . . .	Felspar porphyry with quartz.
*79. Mexico, . . .	North America, . . .	Porphyry.
80. Kreuznach, . . .	Near Mainz on the Rhine, . . .	Porphyry rising out of varie- gated sandstone.
*81. Mont d'Or, . . .	Valley of Dordogne in Auvergne,	Trachytic porphyry.
82-84. Linholzhausen, Oberhausen, and Lohnberg, . . .	Duchy of Nassau, . . .	Pearlstone and Pearlstone con- glomerate.
*85. St Allyre, . . .	Clermont in Auvergne, . . .	Conglomerate with fragments of greenstone, &c.
86. Montabaur, . . .	Duchy of Nassau, . . .	Basalt.
87. Probbach, . . .	Ditto ditto, . . .	Basalt.
88. Koden, . . .	In the Rhongebirge, . . .	Basalt.
*89. & 90. Wolkenstein and Wiesenbad, . .	Saxony, . . .	Foot of basaltic masses with wacke.
*91. & 92. St Mart, Cha- tel Guyon, . . .	Near Clermont in Auvergne, . . .	From below volcanic rocks.
93. & 94. Bar and Vic le Comte, . . .	Auvergne, . . .	Below volcanic rocks. From granite?
95. Weyhers, . . .	Rhongebirge, . . .	An ash-grey lava?

## FROM SECONDARY ROCKS.

NAME.	GEOGRAPHIC POSITION.	GEOGNOSTIC POSITION.
96. Neusalzbrunnen,	Near Waldenbourg, . . .	Old red sandstone.
*97. Luxueil, . . .	Dep. of Upper Saone, France,	Red sandstone of the Vosges.
98. & 99. Altwasser and Chalottenbrunn,	Silesia, . . . . .	Red sandstone and coal forma- tion.
*100. Sonah, . . .	Near Delhi in India, . . .	Ferruginous sandstone.
*101.-103. Catherine's, Paul's and Peter's springs . . .	Caucasian mountains, . . .	Sandstone and sandstone brec- cia.
104. Roisdorf, . .	Near Bonn, . . . . .	Sandstone and bituminous shale.
*105. Setacuna, . .	Banks of the Ganges, . . .	Quartz rock.
*106. & 107. Cransac Sen- zac, &c. . . . .	Dep. of Aveyron, France, . .	Coal formation.
*108. Neris, . . . .	Auvergne, . . . . .	Coal formation.
*109. Kungara, . .	Caucasian mountains, . . .	Indurated slate-clay.
110. Lublo, . . . .	Galician frontier of Hungary, .	Coal sandstone.
111. Vicar's Bridge, .	Clackmannanshire, Scotland, .	Clay ironstone, and bitumi- nous shale of coal formation.
112. & 113. Bonnington, St Bernards, . .	Edinburghshire, Scotland, . .	Coal formation.
114. Hartfell, . . .	Near Moffat, Scotland, . . .	Decomposed alum-slate.
115. Johnstown, . .	County Kilkenny, Ireland, . .	Ferruginous argillaceous slate.
116. Kingswood, . .	Near Bristol, England, . . .	Coal formation.
117.-119. Dobromil, Dobna, Okna, &c.	Hungary, Transylvania, and Moldavia, . . . . .	Coal formation and loose allu- vial sands.
*120. Ussat, . . . .	Dep. of the Arriege, France, .	Limestone with caverns.
*121. St Paul de Fenouil- hede, . . . . .	Eastern Pyrenees, . . . . .	Limestone covering schistose marls.
*122. Dax, . . . . .	Dep. of the Landes, France, .	Compact limestone.
*123. Campagne, . .	Dep. of the Aude, France, . .	Calcareous and aluminous for- mation.
*124. Balaruc, . . .	Near Montpellier, . . . . .	Limestone.
*125. Bagnols, . . .	Dep. of Lozere, France, . . .	Compact limestone (Alpine and Jura).
*126. Bourbonne les Bains, . . . . .	Dep. of Upper Marne, France, Dep. of the Mouths of the Rhone,	Compact Jura limestone.
*127. Aix, . . . . .	Dep. of the Low Alps, France,	Compact Jura limestone.
*128. Greoulx, . . .	Savoy, . . . . .	Jura limestone.
*129. Aix, . . . . .	The Valais, Switzerland, . .	White compact shale limestone.
*130. Leuk, . . . . .		Calcariferous clay-slate and al- pine limestone.
*131. Bobbio, . . . .	Near Genoa, . . . . .	Argillaceous limestone.
*132. Baden, . . . .	Valley of the Limmat, Switzer- land, . . . . .	Jura limestone.
*133. Schinznach, . .	Switzerland, . . . . .	Marly sandstone.
*134. Eisenbach, . .	Near Schemnitz in Hungary, .	Grey compact limestone.
*135. Glashutte, . .	Near Schemnitz in Hungary, .	Grey compact limestone, one spring from calc-tuff.
*136. Mehadia, . . .	In the Bannat, . . . . .	Limestone with caverns.
*137. Buda, . . . . .	Hungary, . . . . .	Argillaceous grey limestone.
*138. Erlau, . . . .	Mountains of Matra, Hungary,	Compact grey limestone.
*139. & 140. Buxton and Matlock, . . . . .	Derbyshire, England, . . . .	Mountain limestone.
*141. Bath, . . . . .	England, . . . . .	Black, sublamellar, lias limest.
*142. Bristol, . . . .	England, . . . . .	Compact limestone (oolite or lias).
*143. Taafe, . . . . .	Valley of Taafe, Wales, . . .	Mountain limestone?
*144. Mallow, . . . .	Ireland, . . . . .	Limestone.
*145. Bonarbashy, . .	Plain of Troas, Asia Minor, .	Puddingstone covered by lime- stone.
146. Barthfeld, . . .	Gallician frontier of Hungary,	Compact limestone.
147. Borsek, . . . .	Transylvania, . . . . .	Compact limestone.
148. Fured, . . . . .	Near Lake Balaton in Hungary,	Compact grey limestone.
149. Pougues, . . . .	Dep. of Nievre in France, . .	Jura limestone or chalk marl.



FROM SECONDARY ROCKS.—*Continued.*

NAME.	GEOGRAPHIC POSITION.	GEOGNOSTIC POSITION.
150. Strathpeffer, .	Ross-shire in Scotland, .	Dark fetid bituminous limestone.
151. Swadlinbar, .	County of Cavan, Ireland, .	Compact fetid limestone.
152.-154. Rosenheim, Reichenhall and Ischl, . . .	Tyrolese Alps, . . . .	Compact limestone, magnesian?
155. Dorfgeismar, .	Near Hofgeismar, Germany, .	Junction of muschelkalkstein with variegated sandstone.
156. Brakel, . . .	Germany, . . . .	Muschelkalkstein.
157. Melksham, .	Wiltshire, England, . . .	Oolite formation.
158.-160. Camerade, Bastide de Serron, Salies, . . .	Pyrenees, . . . .	Ferruginous and marly limestone.
161. Salins, . . .	Dep. of Meurthe and Jura, France, . . . .	Below Jura limestone. From Keuper.
162. Salzuflern, .	Near Pymont in Germany, .	Junction of Keuper with lias.
163. Driburg, . . .	Germany, . . . .	Variegated sandstone.
164. Pymont, . . .	Germany, . . . .	Variegated sandstone.
165. & 166. Kissingen and Bocklet, . .	Franconia, . . . .	Variegated sandstone.
167. & 168. Sondershausen and Lauchstädt, . . .	Germany, . . . .	Variegated sandstone.
169.-171. Northwich, Middlewich, Ashby-de-la-Zouch, .	Cheshire and Leicestershire, England, . . . .	Variegated sandstone.
172.-175. Sackingen, Hub, Naaheim, Salzhausen, . .	Basin of the Lower Rhine, Germany, . . . .	Variegated sandstone.
176. & 177. Artern and Halle, . . . .	Germany, . . . .	Variegated sandstone.
*178. Near River Bagin, .	Bundelcund, India, . . .	Variegated sandstone.
179. Meinberg, . .	Germany, . . . .	Marls, clays, and sandstone of the Keuper.
180. & 181. Vlotho and Valldorf, . . .	Germany, . . . .	Keuper near junction with Muschelkalk.
182. Cheltenham, .	Gloucestershire, England, .	Sand of lias formation.
183.-185. Leamington, Tewksbury, Gloucester, . . . .	Gloucestershire, England, .	Lias clay.
186.-188. Limmer, Nenndorf, Eilsen, . .	Germany, . . . .	Quadersandstone.
189. & 190. Cudowa and Reinerz? . . .	County of Glatz, . . . .	Greensand formation.
191. Tunbridge, . .	Kent, England, . . . .	Siliceous gritty sandstone below chalk.
192. Isle of Wight, .	England, . . . .	Loose ferruginous quartz sandstone below chalk.
193.-196. Unna, Werl, Soest, and Salzkotten, . . . .	Westphalia, Germany, . .	Chalk marl.

## FROM TERTIARY AND ALLUVIAL ROCKS.

*197. St Amand, . .	Belgium, . . . .	Below chalk formation. From coal?
198. Chapelle Godefroy, .	Dep. of Lower Seine, France, .	Chalk, or above it.
199. Roye, . . . .	Picardy, France, . . . .	Chalk, or above it.
200. Epsom, . . . .	Surrey, England, . . . .	Plastic clay.
201. Brighton, . . .	Sussex, England, . . . .	Plastic clay.
202. & 203. Forges and Rheims, . . . .	Dep. of Lower Seine, France, .	Plastic clay.
*204. Sciacca, . . .	Sicily, . . . .	Clay formation.
205. Passy, . . . .	Near Paris . . . .	Below calcaire grossier. From plastic clay?

FROM TERTIARY AND ALLUVIAL ROCKS.—*Continued.*

NAME.	GEOGRAPHIC POSITION.	GEOGNOSTIC POSITION.
206. Provins, . .	Near Fontainebleau, France, . .	Below calcaire grossier. From plastic clay?
207. Tongres, . .	Near Maestricht, . . . .	Limits of chalk and calcaire grossier. Plastic clay?
208. & 209. Arcueil, . .	South of Paris, . . . .	Calcaire grossier.
Sevres, &c. . . .	Dep. of Loiret, France, . .	Calcaire grossier, or above it.
210. Ferrière, . . . .	Near Montmorency, . . . .	Above calcaire grossier. From gypsum formation.
211. Enghien, . . . .	North-west of Montmorency, . .	Below upper sands and sandstones of gypsum formation?
212. Moulignon, . . . .	Duchy of Nassau, . . . .	Porous fresh-water limestone.
213.-215. Weilbach, . .	Auvergne, . . . .	Calc-tuff in a formation of mountain limestone and coal.
Höchst, Nied, . . . .	Near Vienna, . . . .	Calc-tuff.
*216. Vichy, . . . .	Duchy of Nassau, . . . .	Alluvial deposits of Lahn, near clay-slate.
*217. Baden, . . . .	Duchy of Nassau, . . . .	Junction of alluvial deposits with talcose-slate.
*218. Wiesbaden, . . . .	Bohemia, . . . .	Alluvial clay, loam, peat, &c.
*219. Soden, . . . .	County Kilkenny, Ireland, . .	Blue gravel.
220. Franzensbad, . . . .	Mecklenburg and Pomerania, . .	Alluvial sands.
221. Brownstown, . . . .	Germany, . . . .	Alluvial clays and peats.
222-224. Bramstedt, . . . .	Voigtland, . . . .	Marshy plain.
Greifswald, Col- . . . .	Bohemia, . . . .	Marsh superincumbent on granite.
berg, &c. . . .	Bohemia, . . . .	Marshy plateau.
225-229. Fiestel, Reh- . . . .	Near Neusoh in Hungary, . .	Marshy plain surrounded by trachytic conglomerates.
burg, Northeim, . . . .	Yorkshire, England, . . . .	Bog resting on clay and gravel.
Langensalza, . . . .		
Tennstedt, . . . .		
230. & 231. Elster, . . . .		
Brambach, &c. . . .		
232. Marienbad, . . . .		
233. Königswart, . . . .		
234. Hradek, . . . .		
235. Harrowgate, . . . .		

## FROM MODERN VOLCANIC ROCKS.

*236. Pisciarelli, . . . .	Solfatara between Monte Nuovo and Pozzuoli, Italy.
*237. Castellamare, . . . .	East part of Gulf of Naples.
*238. Calvi, . . . .	North of Plain of Capoua.
*239. Santa Venera, . . . .	Bottom of Mount Etna.
*240. Island of Lipari, . . . .	Mediterranean Sea.
*241. Island of Pantellaria, . . . .	Ditto.
*242. Island of Milo, . . . .	Grecian Archipelago.
*243-245. Geyser, Rycum, Reikholt, &c., . . . .	Island of Iceland.
*246. Gurgitello, &c., . . . .	Island of Ischia.
*247 & 248. Cheribon, Bagni Vangni, &c., . . . .	Island of Java.
*249. Island of Amsterdam, . . . .	Indian Ocean.
*250. Rio Vinagre, . . . .	Volcano of Purace, Province of Popayan, South America.
*251. Malpays of Jorullo, . . . .	Mexico.
*252. Island of Pico, . . . .	Group of the Azores.
*253. Island of St Michael, . . . .	Ditto.
*254 & 255. Islands of St Vincent, Guadeloupe, &c. . . .	West Indies, Antilles.
&c. . . .	&c. . . .

- N. B.—1. From the defective indications of the geognostic position of many springs, I have been frequently obliged to give merely the mineralogical title of the rocks from which they issue, without signalling their place in the grand series of formations composing the crust of the earth.
2. The gaseous and solid constituents predominating in the composition of most of the springs in this Table, will be found on referring to the heads of Acids and Gases, and to the sketch of their Geographical Distribution in the body of the Essay.
3. This Table has been constructed chiefly with the view of illustrating Propositions 1, 2, 3, 4, and 5, at pp. 242-244.







7/



